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Attorneys for Plaintiff Diamond Coating Technologies LLC

UNITED STATES DISTRICT COURT

CENTRAL DISTRICT OF CALIFORNIA

SOUTHERN DIVISION

DIAMOND COATING TECHNOLOGIES, LLC,

Plaintiff,

vs.

HYUNDAI MOTOR AMERICA AND HYUNDAI MOTOR COMPANY.

Defendants.

Case No. **SACV13-01480 DOC (DFMx)**

COMPLAINT FOR PATENT INFRINGEMENT

JURY TRIAL DEMANDED

COMPLAINT FOR PATENT INFRINGEMENT

Plaintiff Diamond Coating Technologies LLC files this Complaint for patent infringement against Hyundai Motor America and Hyundai Motor Company (collectively, "Defendants"). Plaintiff Diamond Coating Technologies LLC alleges:

THE PARTIES

1. Plaintiff Diamond Coating Technologies LLC ("DCT") is a limited liability company duly organized and existing under the laws of Delaware with its principal place of business in 3945 Freedom Circle, Suite 900, Santa Clara, CA 95054-1226.

2. DCT is the assignee and owner of two patents at issue in this action, U.S. Patent Nos. 6,071,103 and 6,354,008.

3. DCT is informed and believes, and on that basis alleges, that Defendant Hyundai Motor Company ("HMC") is a Korean corporation having a global headquarters at 231, Yangjae-Dong, Seocho-Gu, Seoul, 137-938, Korea. HMC is the parent corporation of Hyundai Motor America. HMC, through its various entities, designs, manufactures, markets, distributes and sells Hyundai automobiles in California and multiple other locations in the United States and worldwide.

4. DCT is informed and believes, and on that basis alleges, that Hyundai Motor America ("HMA") is a corporation duly organized under the laws of the State of California and having its principal place of business in this District at 3200 Park Center Drive, Costa Mesa, CA 92626. HMA is HMC's headquarters for management of North American operations and manufacturing. HMA manufactures and distributes Hyundai vehicles and sells these vehicles through its network of dealers.

JURISDICTION AND VENUE

5. This Court has subject matter jurisdiction pursuant to 28 U.S.C. §§ 1331 and 1338(a) because this action arises under the patent laws of the United States, 35 U.S.C. §§ 1 et seq.

6. Venue is proper in this federal district pursuant to 28 U.S.C. §§ 1391(b)-(c) and 1400(b).

7. Defendant HMA is headquartered in this District. Defendants have done business in this District, have sold infringing products in this District, and continue to sell infringing products in this District, entitling DCT to relief.

INFRINGEMENT OF U.S. PATENT NO. 6,071,103

8. On June 6, 2000, United States Patent No. 6,071,103 (the "'103 patent") was duly and legally issued for an invention entitled "Member Having Sliding Contact Surface, Compressor and Rotary Compressor." DCT was later assigned the '103 patent and continues to hold all rights and interest in the '103 patent. A true and correct copy of the '103 patent is attached hereto as Exhibit A.

9. Defendants have infringed and continue to infringe the '103 patent. Defendants manufacture, sell, import and/or offer for sale Hyundai vehicles utilizing parts coated with infringing hard carbon films. For example, defendants sell vehicles with engines containing parts, including, but not limited to, valve lifters and pistons, with infringing hard carbon film coatings. The use of hard carbon film coatings allows for a reduction of engine friction, wear reduction, and improved engine fuel efficiency. DCT is informed and believes, and on that basis alleges, that Hyundai engine models containing parts with infringing hard carbon film coatings include, but are not limited to, Gamma 1.4/1.6 L, Theta 2.0/2.4L, Theta II 2.0/2.4 L, Tau 4.6/5.0 L. DCT expressly also accuses all Hyundai engine models not identified above that use the infringing hard carbon film coating. Defendants' vehicles with engines and other components containing parts with hard carbon film coating infringe the '103 patent under 35 U.S.C. § 271.

10. Defendants' acts of infringement have caused damage to DCT, and DCT is entitled to recover from Defendants the damages sustained by DCT as a result of Defendants' wrongful acts in an amount subject to proof at trial. Defendants' infringement of DCT's exclusive rights under the '103 patent will continue to damage DCT, causing irreparable harm for which there is no adequate remedy at law, unless enjoined by this Court.

INFRINGEMENT OF U.S. PATENT NO. 6,354,008

11. On March 12, 2002, United States Patent No. 6,354,008 (the "'008 patent") was duly and legally issued for an invention entitled "Sliding Member, Inner and Outer Blades of an Electronic Shaver and Film-Forming Method." DCT was later assigned the '008 patent and continues to hold all rights and interest in the '008 patent. A true and correct copy of the '008 patent is attached hereto as Exhibit B.

12. Defendants have infringed and continue to infringe the '008 patent. Defendants manufacture, sell, import and/or offer for sale Hyundai vehicles utilizing parts coated with infringing hard carbon films. For example, defendants sell vehicles with engines containing parts, including, but not limited to, valve lifters and pistons, with infringing hard carbon film coatings. The use of hard carbon film coatings allows for a reduction of engine friction, wear reduction, and improved engine fuel efficiency. DCT is informed and believes, and on that basis alleges, that Hyundai engine models containing parts with infringing hard carbon film coatings include, but are not limited to, Gamma 1.4/1.6 L, Theta 2.0/2.4L, Theta II 2.0/2.4 L, Tau 4.6/5.0 L. DCT expressly also accuses all Hyundai engine models not identified above that use the infringing hard carbon film coating. Defendants' vehicles with engines and other components containing parts with hard carbon film coating infringe the '008 patent under 35 U.S.C. § 271.

13. Defendants' acts of infringement have caused damage to DCT, and DCT is entitled to recover from Defendants the damages sustained by DCT as a

result of Defendants' wrongful acts in an amount subject to proof at trial. Defendants' infringement of DCT's exclusive rights under the '008 patent will continue to damage DCT, causing irreparable harm for which there is no adequate remedy at law, unless enjoined by this Court.

WILLFUL INFRINGEMENT

14. Upon information and belief, the Defendants' infringement of any or all of the above-named patents is willful and deliberate, entitling DCT to increased damages under 35 U.S.C. § 284 and to attorney's fees and costs incurred in prosecuting this action under 35 U.S.C. § 285.

15. Defendants had prior knowledge of the patented technology because DCT provided notice of the patents to Defendants in 2012.

JURY DEMAND

16. DCT demands a trial by jury on all issues.

PRAYER FOR RELIEF

WHEREFORE, Plaintiff DCT requests entry of judgment in its favor and against Defendants as follows:

a) Declaration that Defendants have infringed directly, and/or indirectly, U.S. Patent Nos. 6,071,103 and 6,354,008;

b) Permanently enjoining Defendants and their respective officers, agents, employees, and those acting in privity with them, from further infringement, contributory infringement and/or inducing infringement of U.S. Patent Nos. 6,071,103 and 6,354,008;

c) Awarding the damages arising out of Defendants' infringement of U.S. Patent Nos. 6,071,103 and 6,354,008, including enhanced damages pursuant to 35 U.S.C. § 284 together with prejudgment and post-judgment interest, in an amount according to proof;

d) An award of attorney's fees pursuant to 35 U.S.C. § 285 or as otherwise permitted by law; and

e) For such other costs and further relief as the Court may deem just and proper.

Dated: September 23, 2013

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OLEG ELKHUNOVICH
JOSEPH S. GRINSTEIN
SUSMAN GODFREY L.L.P.

By: Kathryn P. Hoek
Kathryn P. Hoek
Attorneys for Plaintiff DCT

Exhibit A

US006071103A

United States Patent [19]

Hirano et al.

[11] **Patent Number: 6,071,103**

[45] **Date of Patent: Jun. 6, 2000**

[54] **MEMBER HAVING SLIDING CONTACT SURFACE, COMPRESSOR AND ROTARY COMPRESSOR**

[75] Inventors: **Hitoshi Hirano**, Nishinomiya; **Keiichi Kuramoto**, Kadoma; **Yoichi Domoto**, Hirakata; **Naoto Tojo**, Ikoma, all of Japan

[73] Assignee: **Sanyo Electric Co., Ltd.**, Osaka, Japan

[21] Appl. No.: **08/895,999**

[22] Filed: **Jul. 17, 1997**

[30] **Foreign Application Priority Data**

Jul. 18, 1996 [JP] Japan 8-189627
Jun. 30, 1997 [JP] Japan 9-174276

[51] **Int. Cl.**[7] **F04C 18/356**; F04C 29/00; B32B 9/00

[52] **U.S. Cl.** **418/63**; 418/152; 418/178; 428/408

[58] **Field of Search** 418/152, 178, 418/63; 428/408

[56] **References Cited**

U.S. PATENT DOCUMENTS

4,842,937	6/1989	Meyer et al.	428/408
5,021,629	6/1991	Shimomura	418/178
5,237,967	8/1993	Willermet et al.	428/408

FOREIGN PATENT DOCUMENTS

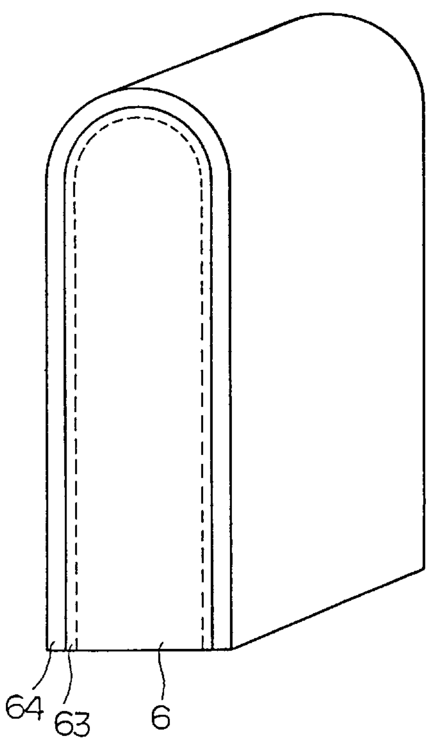
8-177772	7/1996	Japan .

Primary Examiner—John J. Vrablik
Attorney, Agent, or Firm—Arent Fox Kintner Plotkin & Kahn

[57] **ABSTRACT**

A member is disclosed which includes a hard carbon film provided through an interlayer or directly on a main body such as a vane. A mixed layer is formed within the main body or interlayer adjacent to an outer surface of the main body or interlayer. The mixed layer contains carbon and a constituent element of either the main body or the interlayer. The mixed layer has a carbon content gradient in its thickness direction so that a carbon content in a thickness portion thereof closer to an outer surface of the mixed layer is higher than in a thickness portion thereof remoter from the outer surface of the mixed layer.

11 Claims, 19 Drawing Sheets



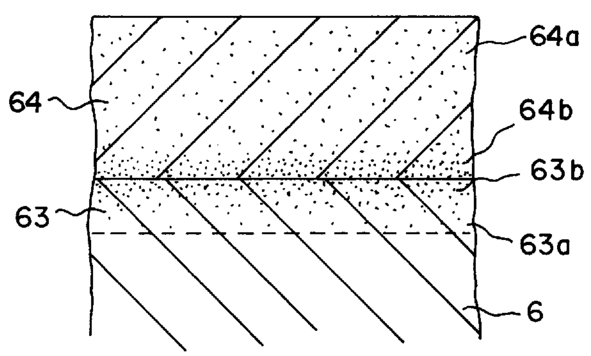


FIG. 1

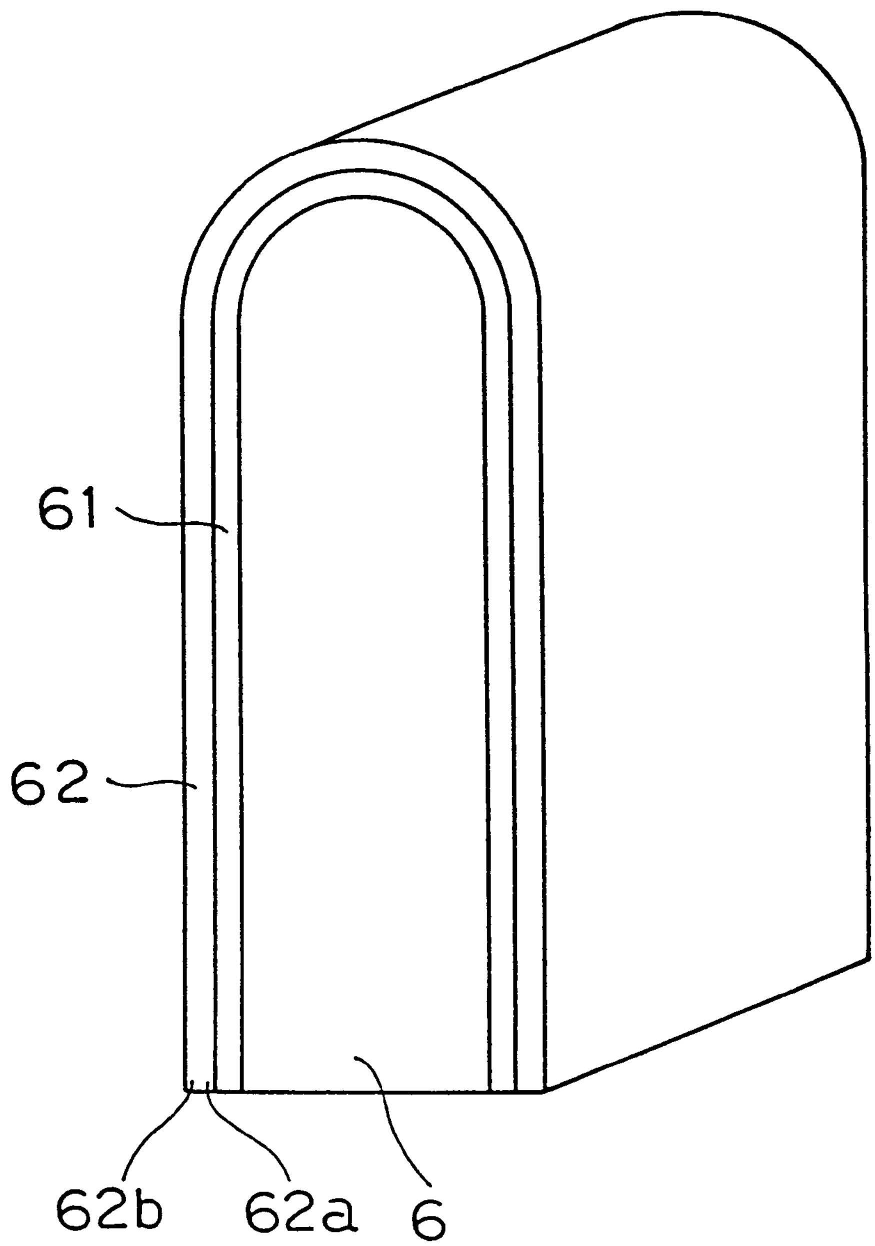


FIG. 2

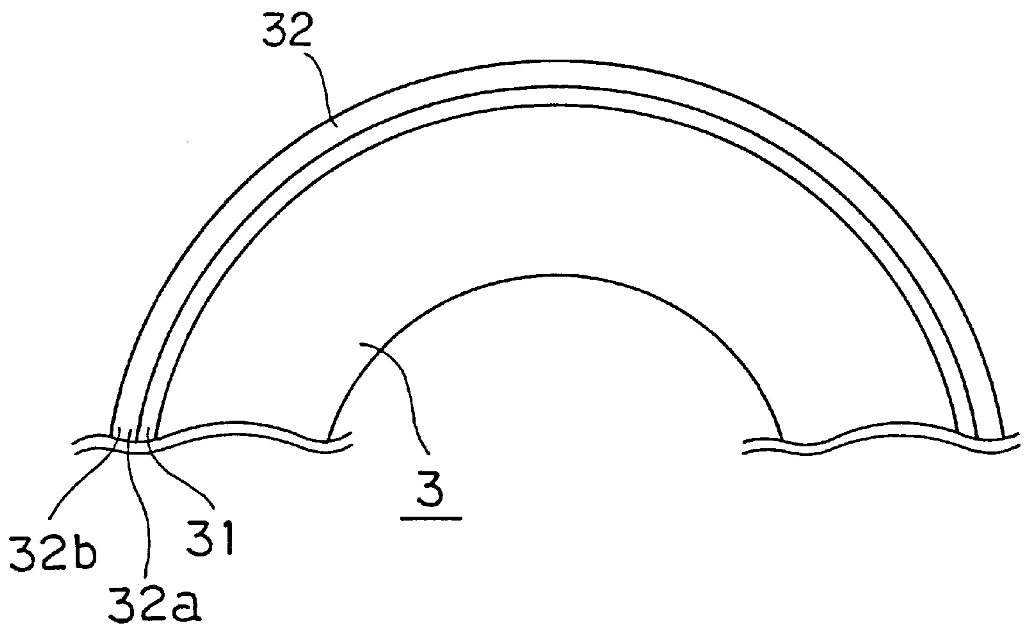


FIG. 3

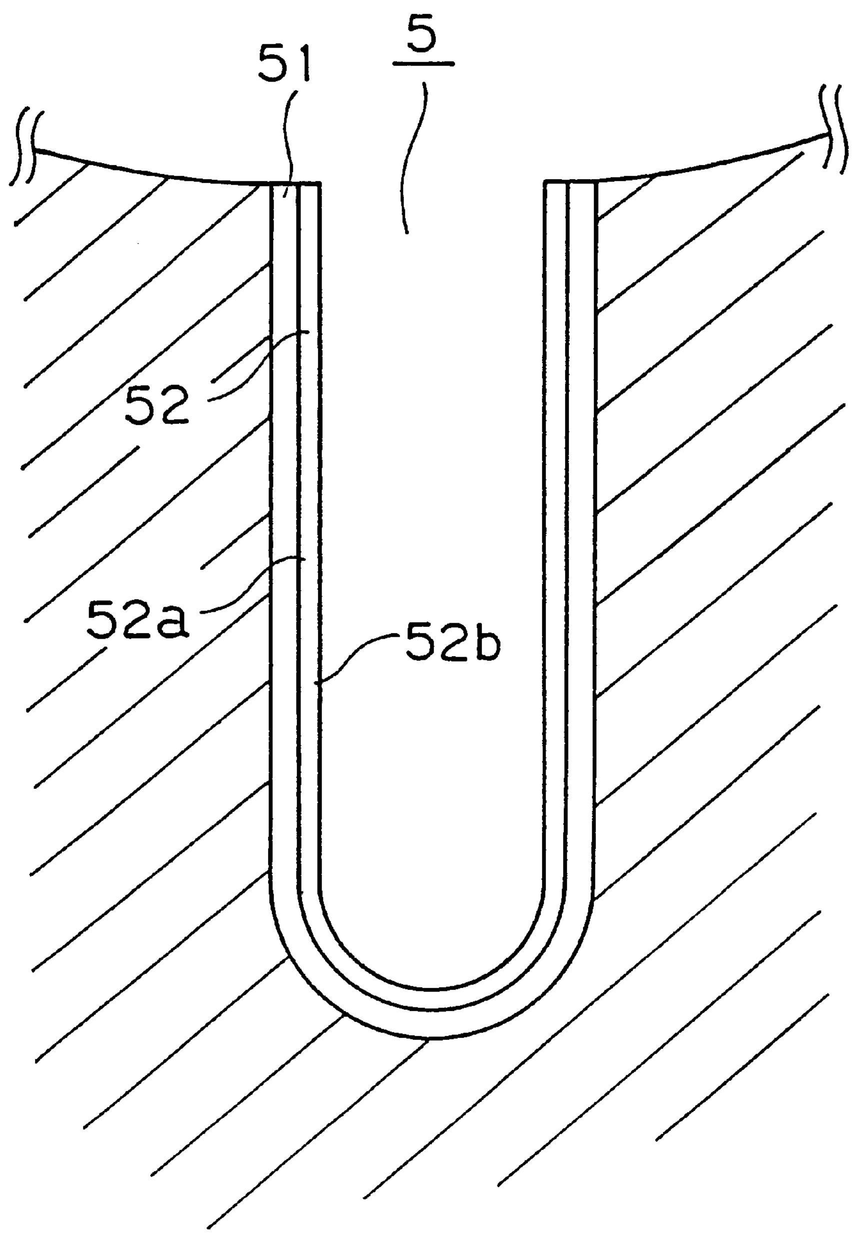


FIG. 4

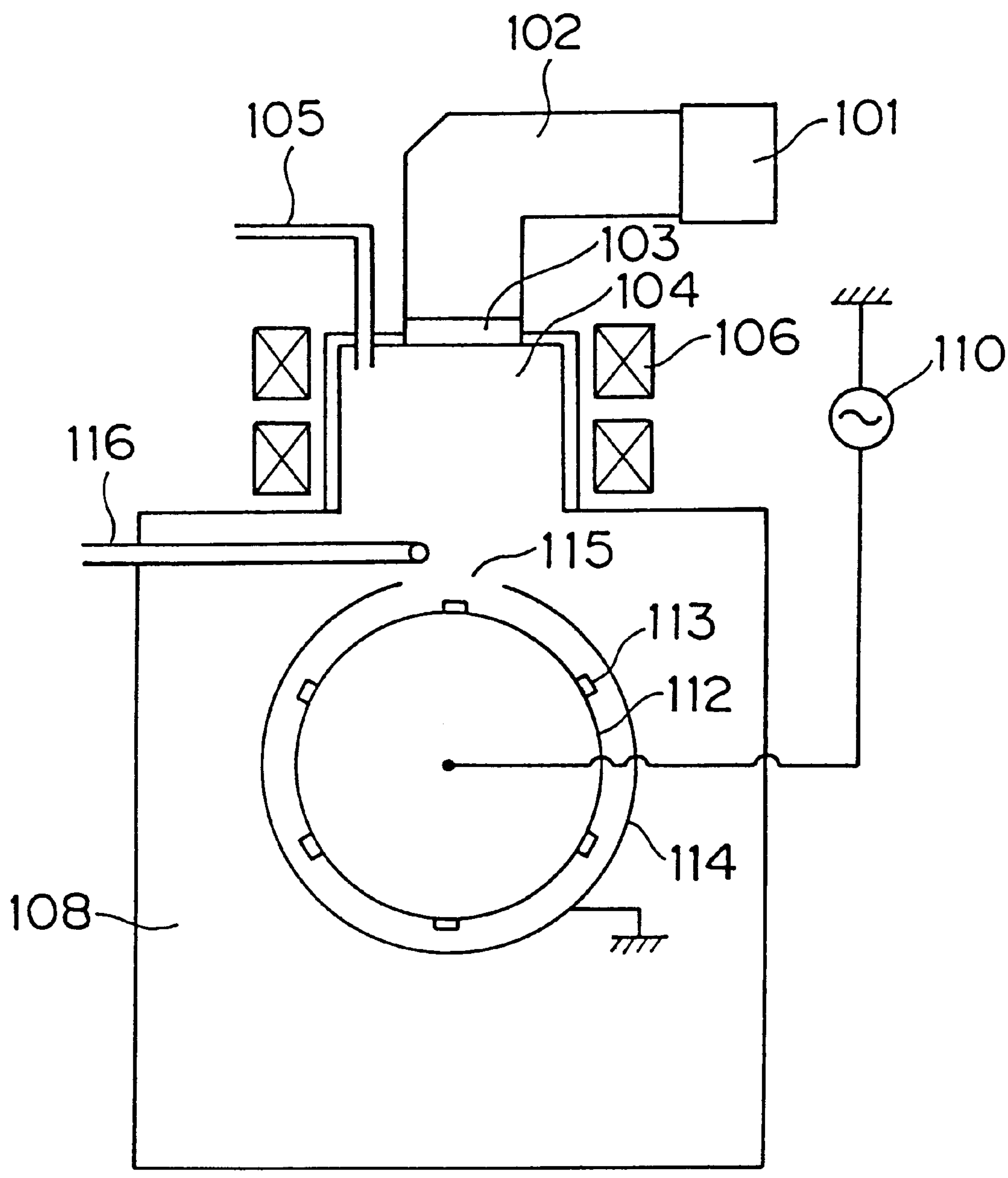


FIG. 5

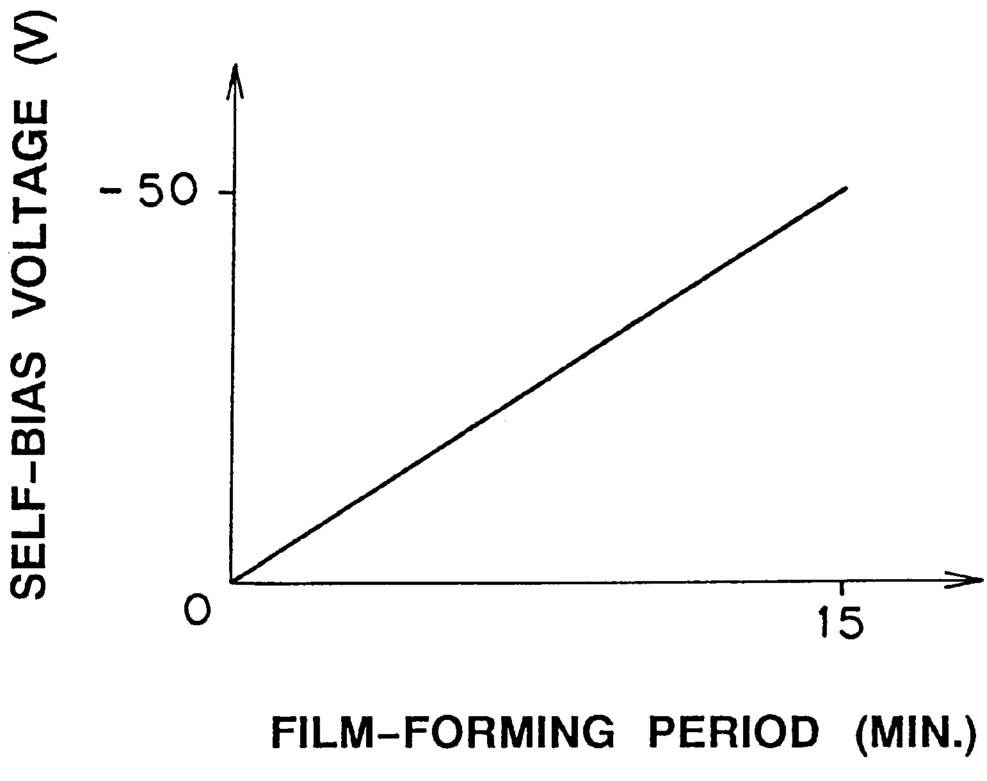


FIG. 6

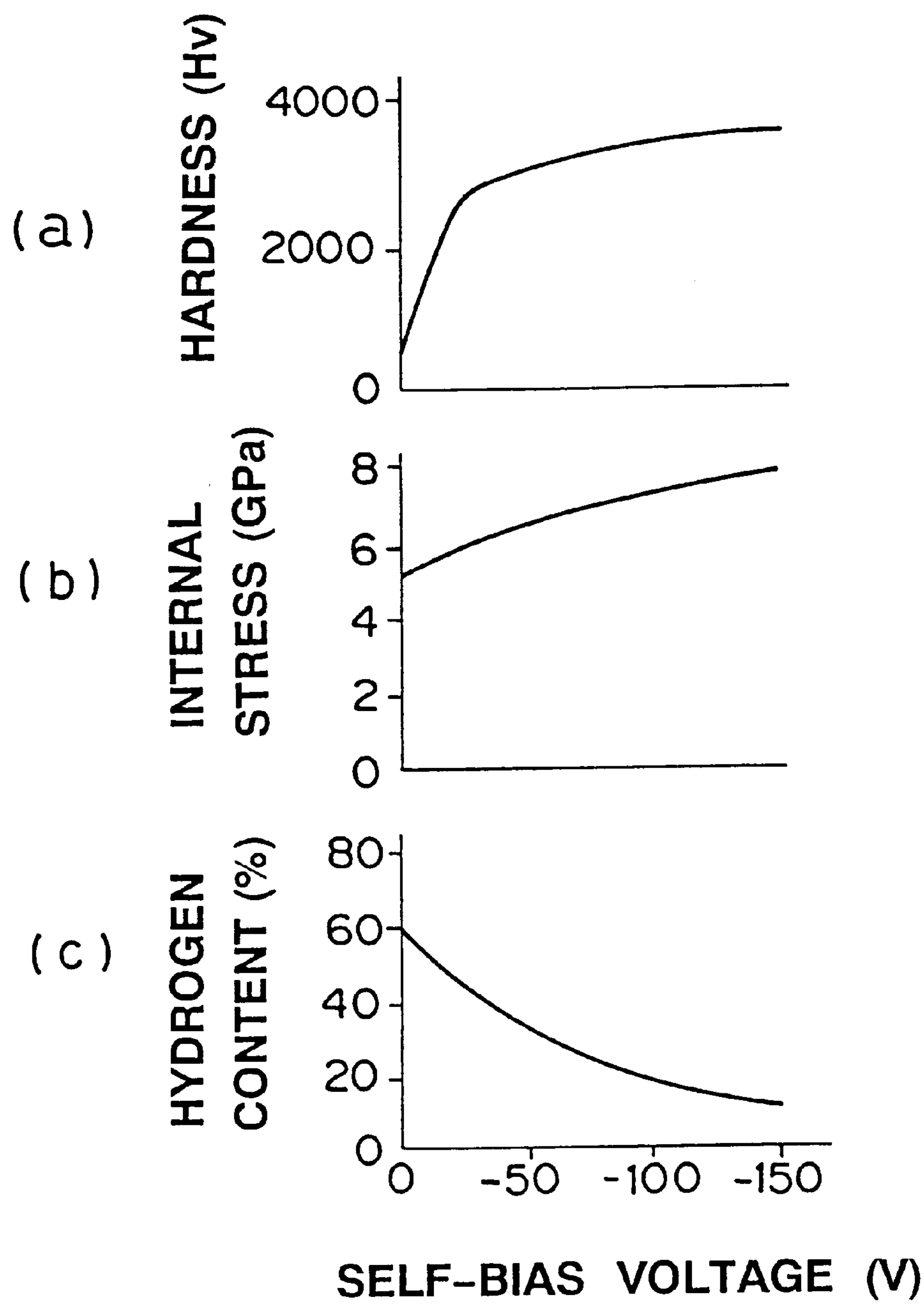

(a)
HARDNESS (Hv)
4000
2000
0
(b)
INTERNAL STRESS (GPa)
8
6
4
2
0
(c)
HYDROGEN CONTENT (%)
80
60
40
20
0
0
-50
-100
-150
SELF-BIAS VOLTAGE (V)

FIG. 7

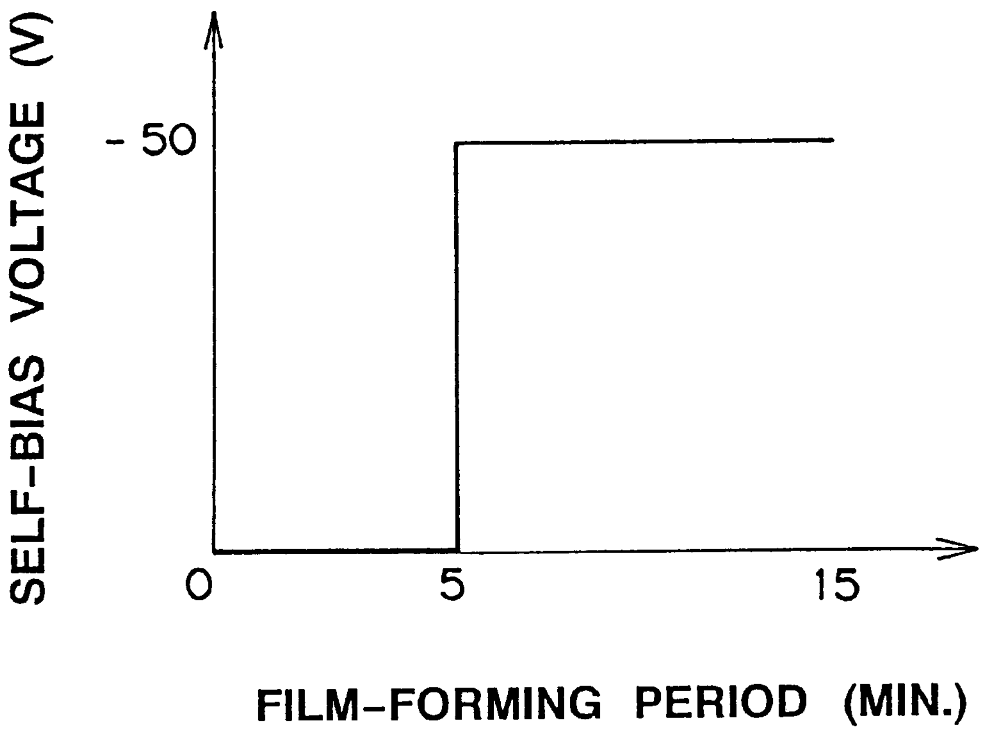


FIG. 8

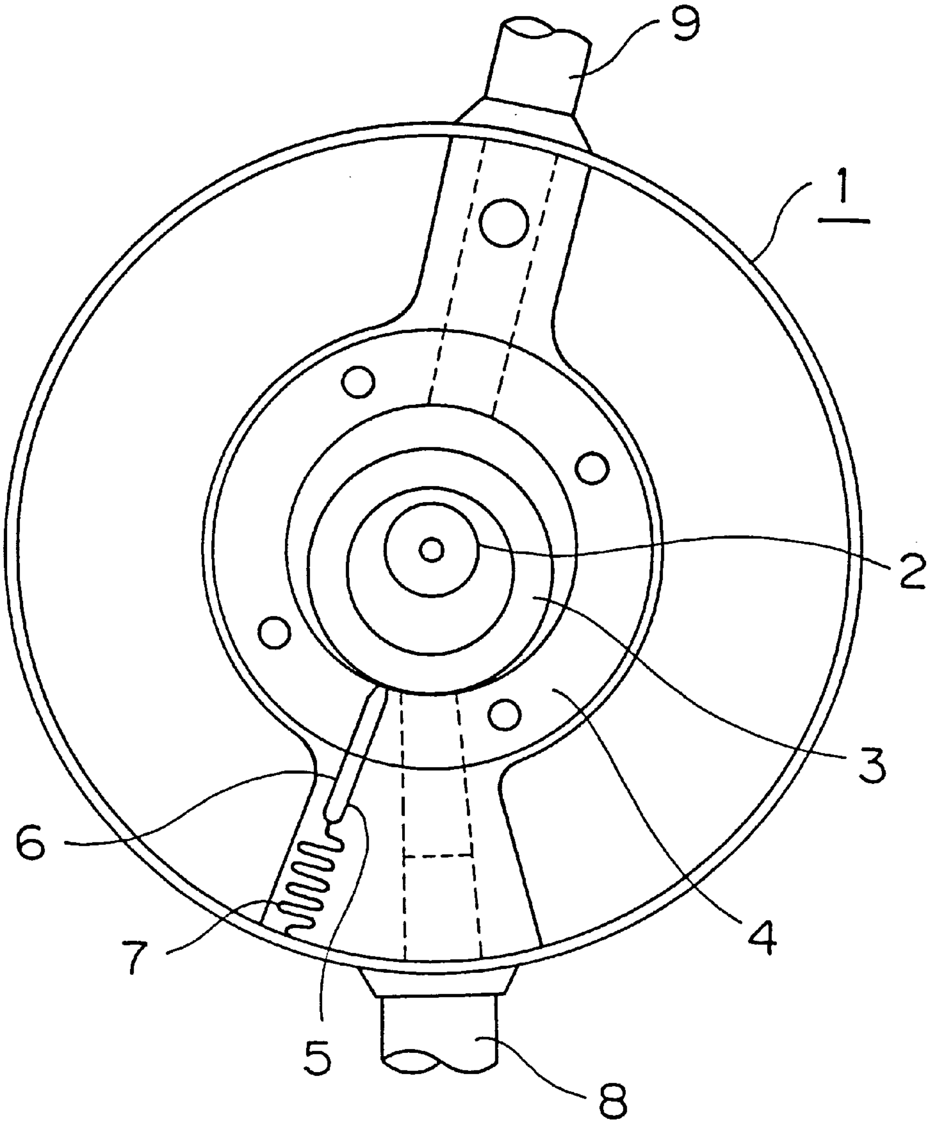


FIG. 9

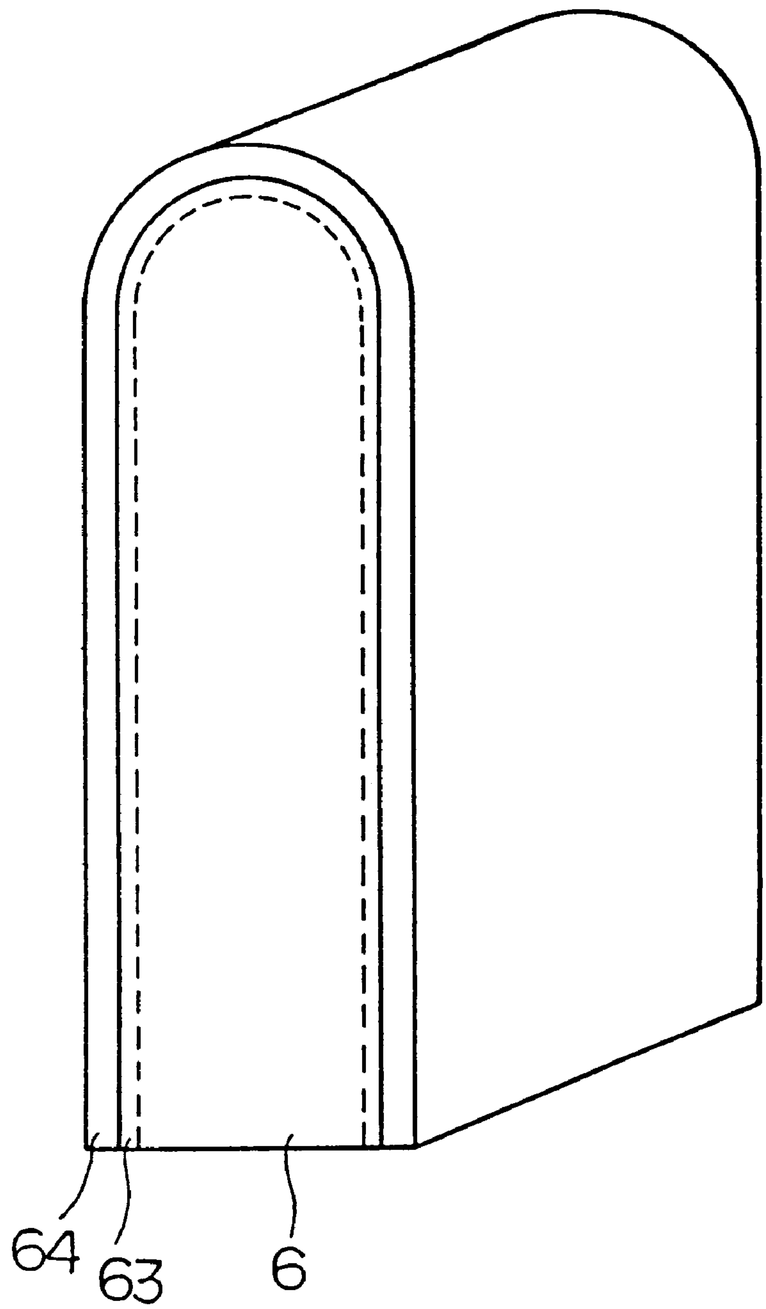


FIG. 10

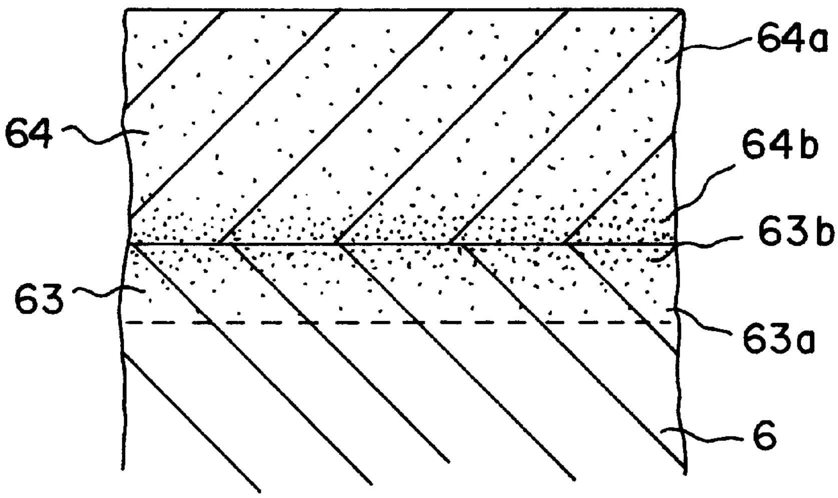

64a
64
64b
63b
63
63a
6

FIG. 11

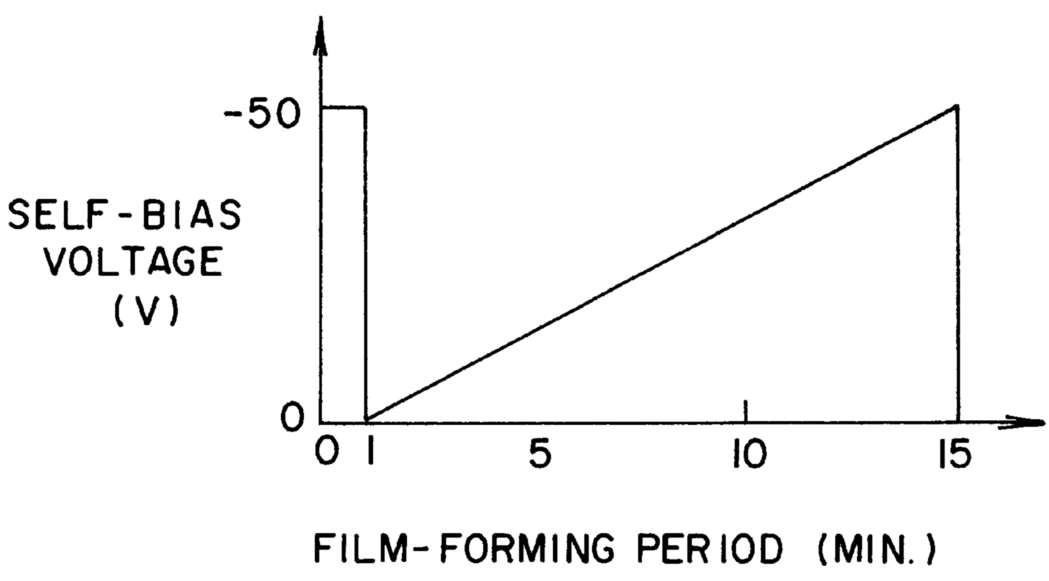

-50
SELF-BIAS
VOLTAGE
(V)
0
0
1
5
10
15
FILM-FORMING PERIOD (MIN.)

FIG. 12

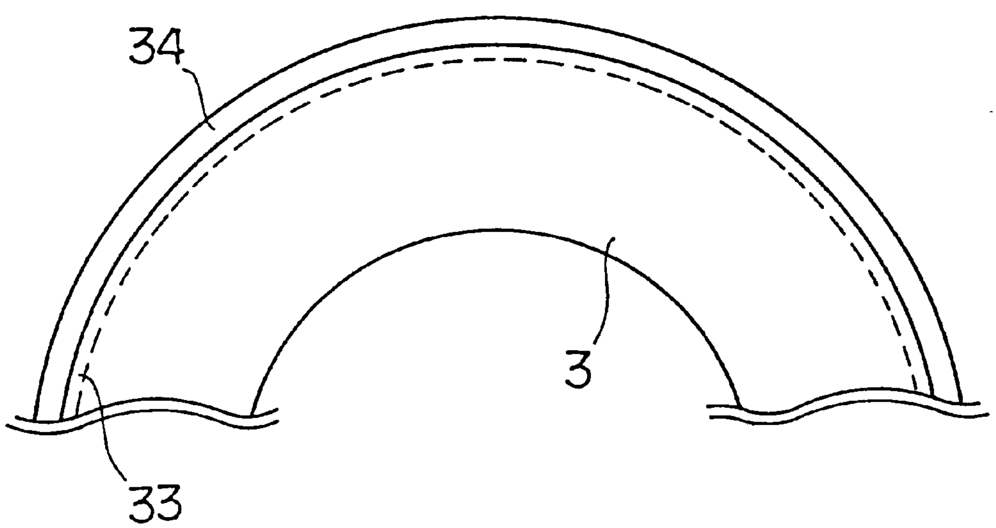


FIG. 13

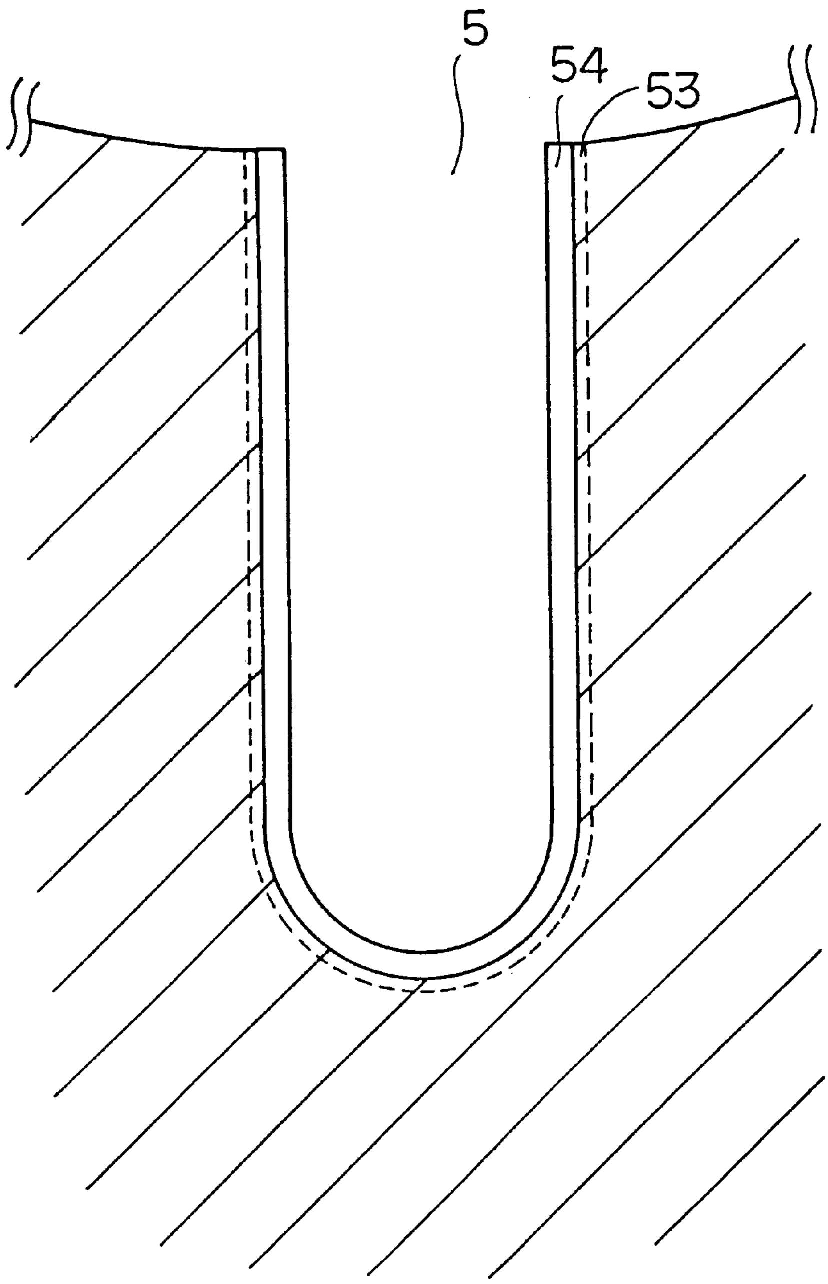


FIG. 14

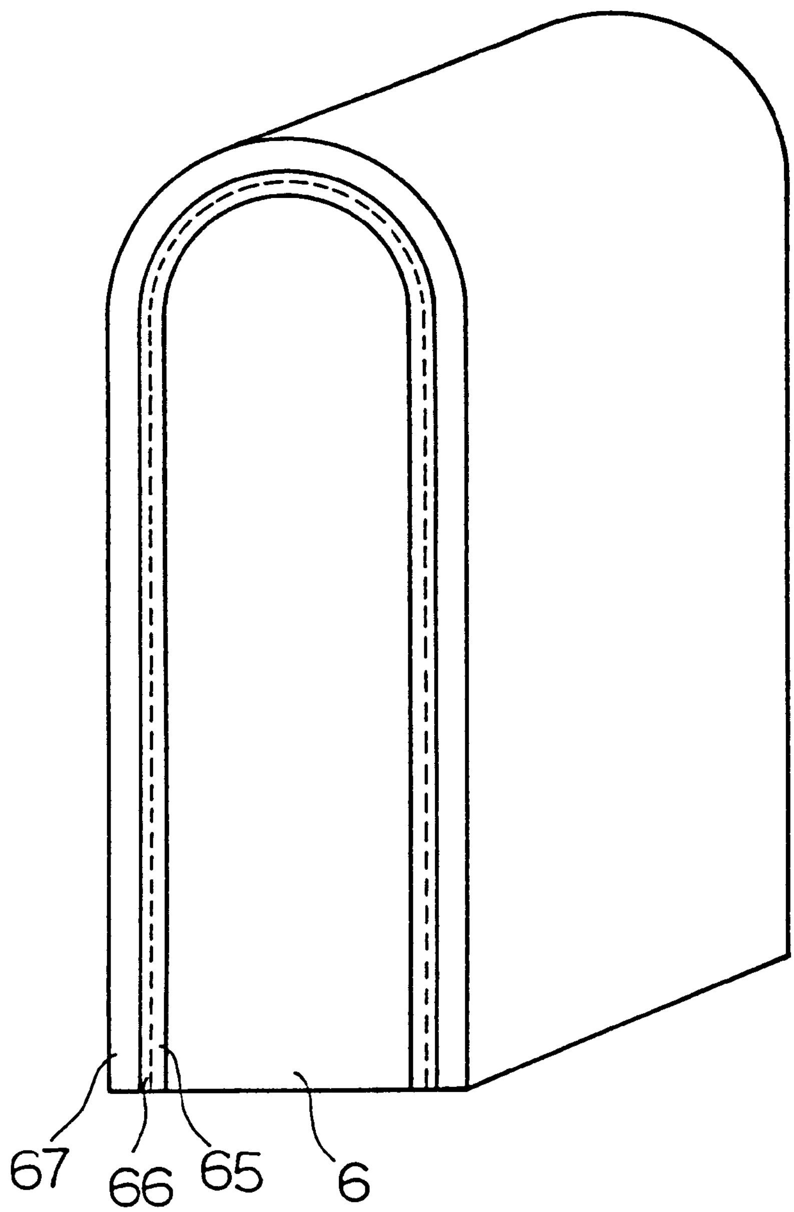


FIG. 15

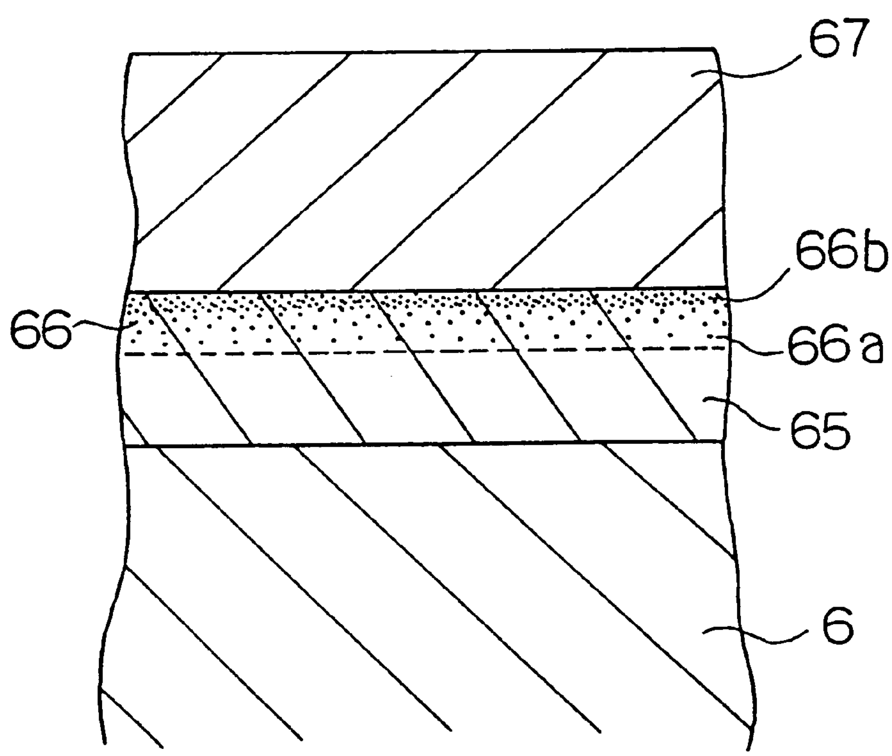
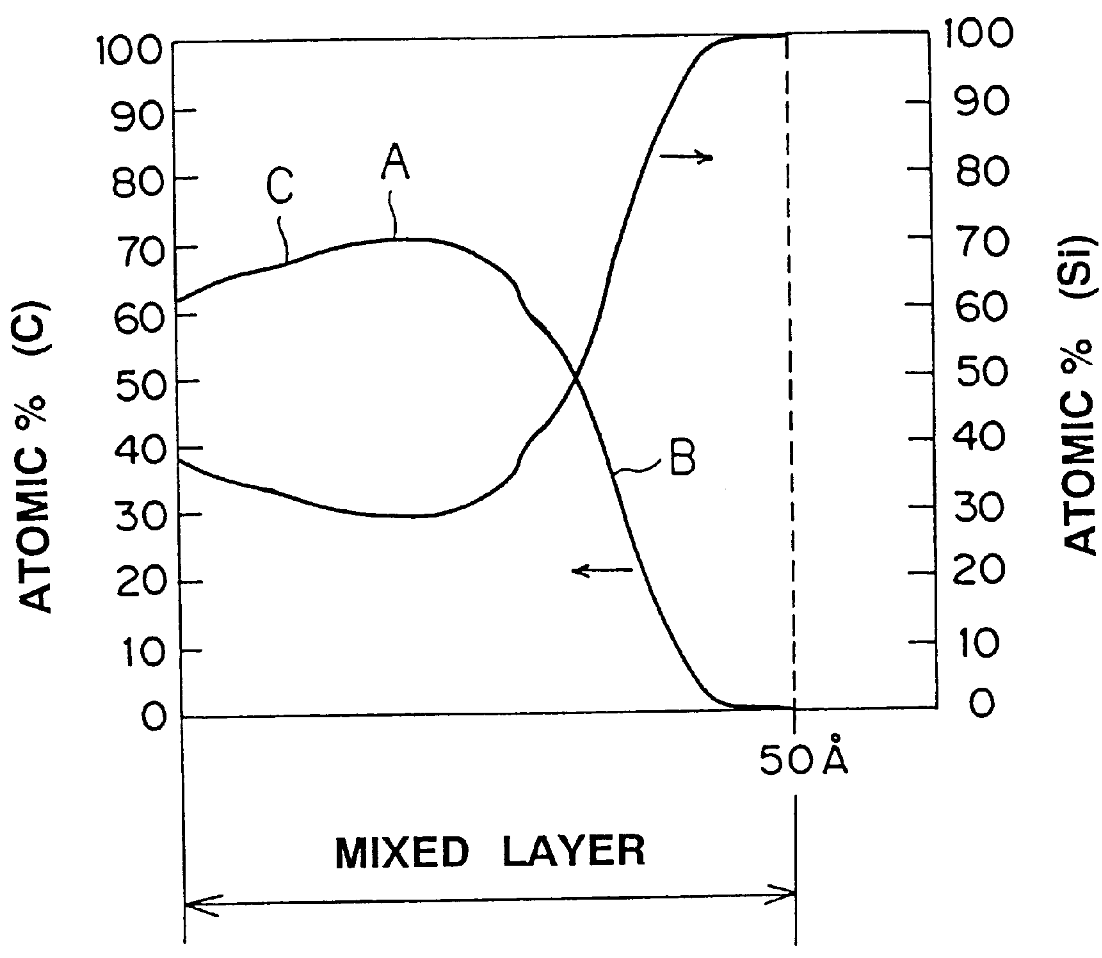


FIG. 16



100
90
80
70
60
50
40
30
20
10
0
ATOMIC % (C)
C
A
B
ATOMIC % (Si)
50Å
MIXED LAYER

FIG. 17

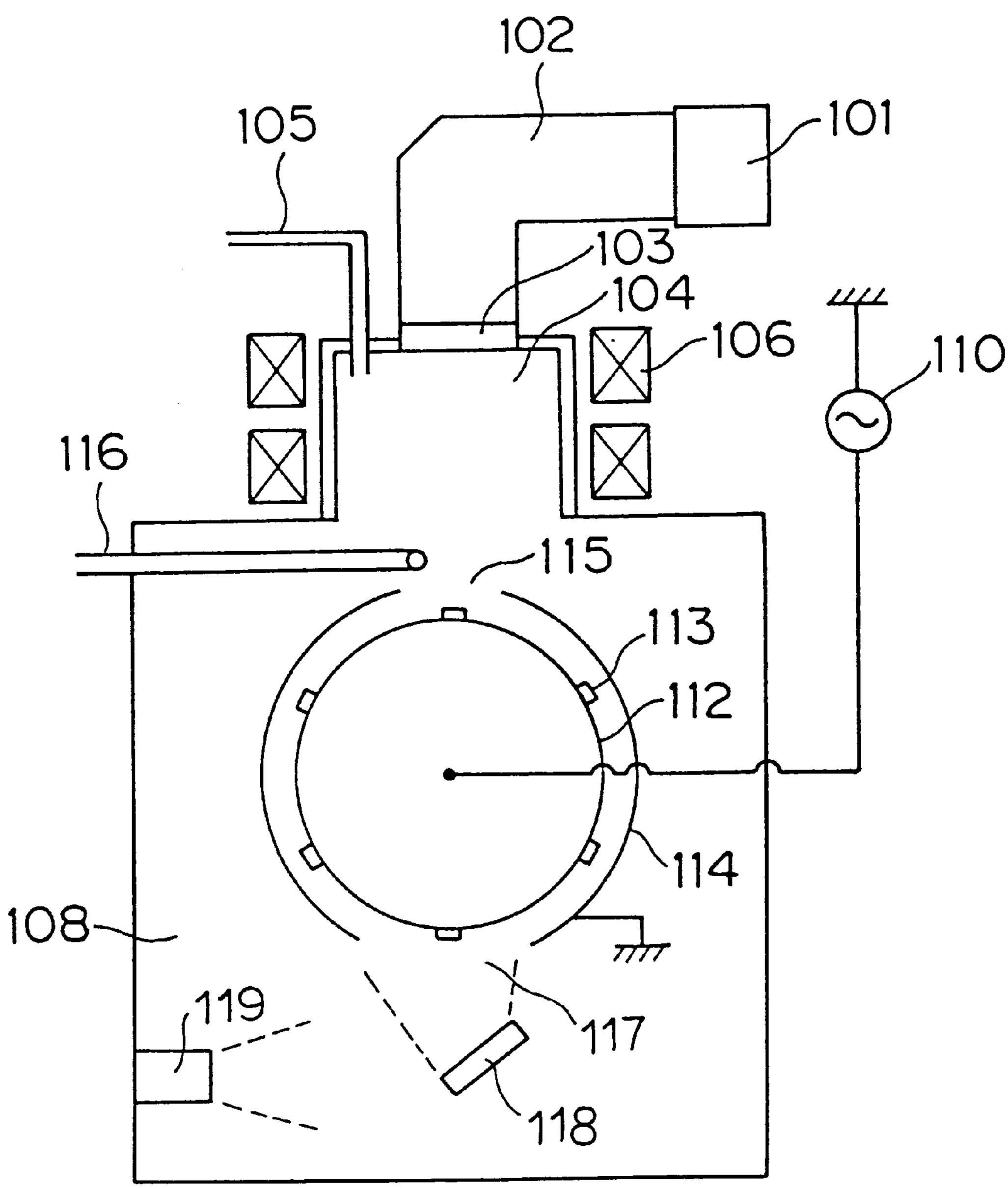


FIG. 18

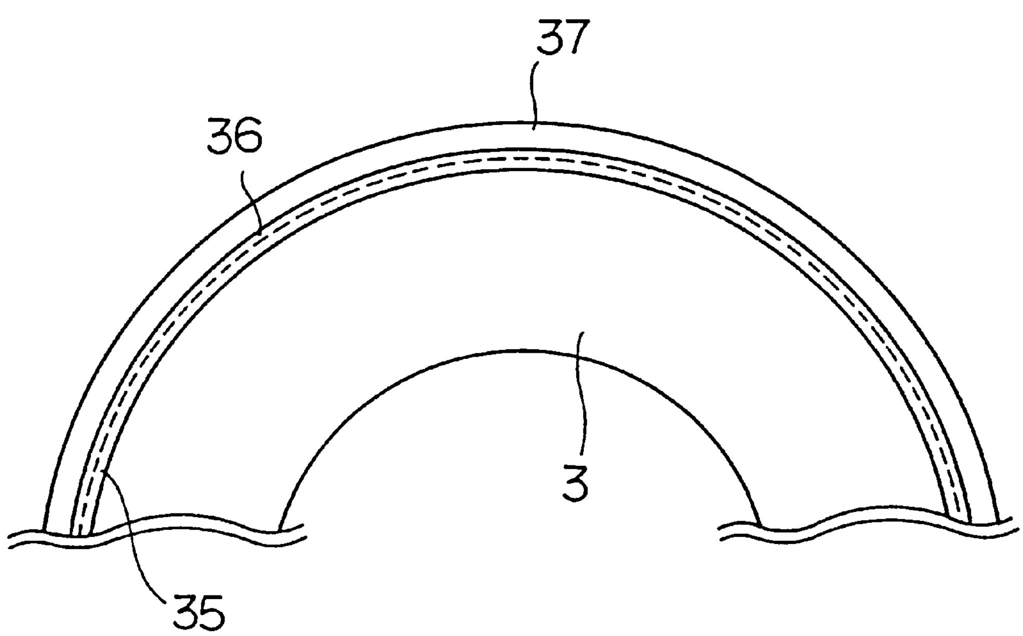


FIG. 19

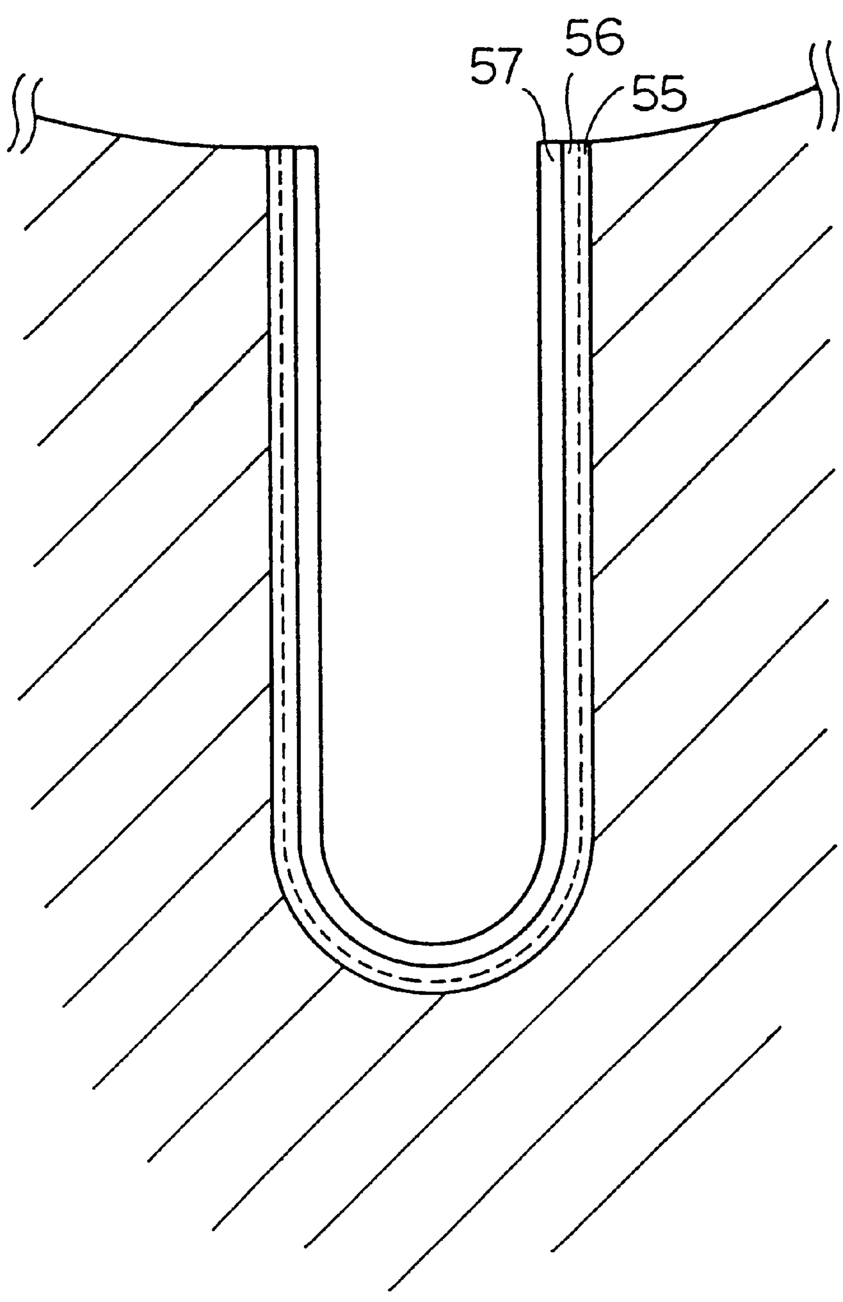
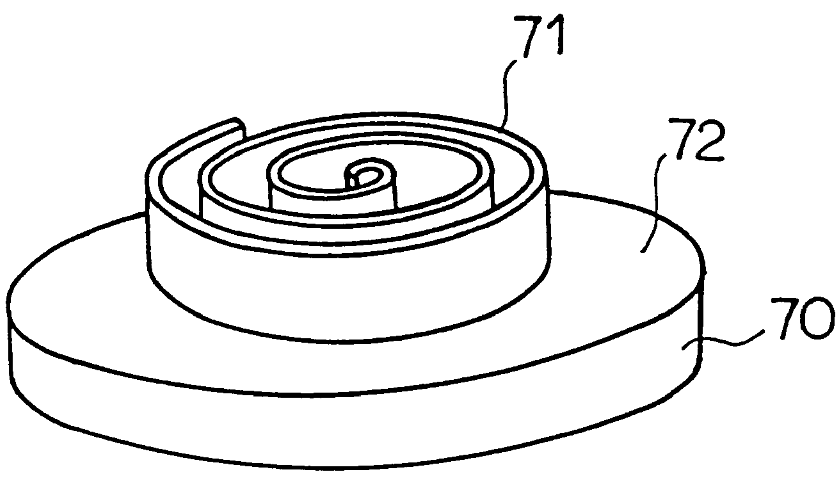


FIG. 20



MEMBER HAVING SLIDING CONTACT SURFACE, COMPRESSOR AND ROTARY COMPRESSOR

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a member having a sliding contact surface, a compressors and a rotary compressor respectively incorporating the member.

2. Description of Related Art

The rotary compressors for use in refrigerating facilities, air-conditioning equipments and the like have been placed under heavier duty conditions with their recent improvements in performance and capability.

In such rotary compressors, a leading end of a vane is brought into constant contact with a peripheral sliding portion of a roller such as by biasing means. This disadvantageously produces sludges interior of a cylinder housing the vane and the roller. These sludges cause blockages in a refrigeration system, specifically in a capillary tube to result in a reduced refrigeration capability of the system.

When the situation goes worst, it possibly becomes impossible to supply a refrigerant carrier through the capillary tube to thereby give a destructive damage to the rotary compressor.

Accordingly, there remains a need to provide a member having a sliding contact surface, such as for use in compressors, rotary compressors and the like, which produces less sludges and has an improved wear resistance relative to conventional members and which can be steadily used for a prolonged period of time.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a member having a sliding contact surface which has a superior wear resistance and is steadily workable for a long period of time, and to provide a compressor and a rotary compressor using such a member.

In accordance with a first aspect of the present invention, a member is provided which includes a main body having a sliding contact surface, a hard carbon film provided on the sliding contact surface and a mixed layer formed within a thickness region of the main body adjacent to the sliding contact surface. The mixed layer is comprised of carbon and a constituent element present in the thickness region of the main body and has a carbon content gradient in its thickness direction so that a carbon content in a thickness portion thereof closer to an outer surface of the mixed layer is higher than in a thickness portion thereof remoter from the outer surface of the mixed layer.

In a preferred embodiment of the invention in accordance with the first aspect, the mixed layer is formed by introducing carbon into the region within the main body and adjacent to the sliding contact surface thereof.

The member in accordance with the first aspect has the hard carbon film on the sliding contact surface to exhibit an excellent wear resistance. Also, the formation of the mixed layer adjacent to the sliding contact surface of the main body provides a good adherence of the main body to the hard carbon film so that the member can be steadily used for a prolonged period of time without experiencing delamination.

In accordance with a second aspect of the present invention, a member is provided which includes a main body having a sliding contact surface, an interlayer provided on the sliding surface of the main body, a hard carbon film provided on the interlayer and a mixed layer formed within a thickness region of the interlayer and adjacent to an outer surface of the interlayer. The mixed layer is comprised of carbon and a constituent element of the interlayer and has a graded carbon content in its thickness direction so that a carbon content in a thickness portion closer to an outer surface of the mixed layer is higher than in a thickness portion remoter from the outer surface of the mixed layer.

In a preferred embodiment in accordance with the second aspect, the mixed layer is formed by introducing carbon into an interlayer region adjacent to the outer surface of the interlayer.

The interlayer may be formed of Si, Ti, Zr, Ge, Ru, Mo, W, or oxides, nitrides or carbides thereof, for example.

The member in accordance with the second aspect provides the hard carbon film on the sliding contact surface through the interlayer to exhibit a superior wear resistance. The formation of the interlayer between the hard carbon film and the main body provides an improved adhesion between the hard carbon film and the main body. Also, the formation of the mixed layer within the interlayer adjacent to its outer surface imparts a further improvement in the adhesion of the hard carbon film.

The term "present invention" will be hereinafter used to explain the matters common to the first and second aspects of the present invention.

In the present invention, the mixed layer is formed adjacent to the sliding contact surface of the main body or to the outer surface of the interlayer. The thickness of the mixed layer is preferably not less than 5 Å, more preferably in the range of 5 Å–1 μm, still more preferably in the range of 10 Å–200 Å. If the mixed layer is thinner, the expected improvement in adhesion may not result. If the thickness of the mixed layer exceeds 1 μm, the adhesion can not be necessarily improved in proportion to the thickness increment.

In the present invention, the mixed layer has a carbon content gradient in its thickness direction so that a carbon content in a thickness portion thereof adjacent or closer to its outer surface is higher than in a thickness portion thereof opposite to or remoter from its outer surface. The mixed layer has a concentrated portion having a maximum carbon content within the mixed layer. Such a concentrated portion is preferably present on the outer surface of the mixed layer or within a thickness region occupying 50% or less of a total thickness of the mixed layer from its outer surface. The carbon content in the concentrated portion of the mixed layer is preferably not smaller than 20 atomic percent, more preferably not smaller than 40 atomic percent.

As described above, it is preferable to form the mixed layer by introducing carbon into the region within the main body adjacent to its outer surface or into the region within the interlayer adjacent to its outer surface. Such an introduction of carbon can be effected by imparting a kinetic energy to active species of carbon such as carbon ions and allowing them to strike on the outer surface of either the main body or the interlayer. Specifically, the carbon introduction can be effected by allowing the carbon ions to strike on an outer surface of a substrate to which a negative self-bias voltage is being applied.

The hard carbon film in the present invention may comprise a diamond thin film, a film having a mixed diamond and amorphous structure, or an amorphous thin carbon film. The film having the mixed structure and the amorphous

carbon film are those generally termed as diamond-like carbon films. The diamond-like carbon film generally contains hydrogen. The diamond-like film with a smaller hydrogen content exhibits an increased hardness and improved wear resistance. On the other hand, the diamond-like carbon film with a larger hydrogen content exhibits an reduced internal stress and improved adherence to an underlayer. It is accordingly preferred that the hard carbon film in accordance with the present invention has a hydrogen content gradient in its thickness direction so that a hydrogen content in a thickness portion thereof remoter from its outer surface is higher than in a thickness portion thereof closer to its outer surface. The provision of such a hydrogen content gradient imparts to the resulting hard carbon film the improved wear resistance and adherence to the underlayer. In the present invention, the hard carbon film may contain at least one additive element selected from the group consisting of Si, N, Ta, Cr, F and B. The inclusion of such an additive element results in a reduced friction coefficient and enhanced wear resistance of the hard carbon film. The inclusion of the additive element is preferably in the range of 3–60 atomic percent, more preferably in the range of 10–50 atomic percent. It is also preferred that the hard carbon film has a content gradient of the additive element in its thickness direction so that a content of the additive element in a thickness portion of the hard carbon film adjacent to its outer surface is higher than in a thickness portion thereof remoter from its outer surface. The provision of such a content gradient within the hard carbon film reduces the friction coefficient of the thickness portion adjacent to its outer surface and thereby enhances its wear resistance film more effectively.

The compressor of the present invention is characterized by employing the above-described member having a sliding contact surface of the present invention. In an exemplary case of a reciprocating compressor having a cylinder and a piston, the present invention is applicable to the cylinder having an inner peripheral surface for providing a sliding contact surface, and/or the piston having an outer peripheral surface for providing a sliding contact surface. In accordance with the first aspect, the hard carbon film is provided on the inner peripheral surface of the cylinder and the mixed layer is formed within the cylinder adjacent to its inner peripheral surface. The hard carbon film is also formed on the outer peripheral surface of the piston and the mixed layer is formed within the piston adjacent to its outer peripheral surface. In accordance with the second aspect, the interlayer is placed on the inner peripheral surface of the cylinder. The mixed layer is formed within the interlayer adjacent to its outer surface and the hard carbon film is provided on the interlayer. In case of the piston, the interlayer is placed on the outer peripheral surface of the piston. The mixed layer is formed within the interlayer adjacent to its outer surface and the hard carbon film is provided on the interlayer.

In one embodiment of the rotary compressor in accordance with the present invention, a vane constitutes a main body of the member of the present invention to define a sliding contact surface at its leading end or side portion. In the first aspect, a hard carbon film is provided at least on the leading end or side portion of the vane. A mixed layer is formed within the vane adjacent at least to an outer surface of the leading end or side portion of the vane. In the second aspect, an interlayer is provided at least on the leading end or side portion of the vane, and the hard carbon film is provided on the interlayer. The mixed layer is formed within the interlayer adjacent to its outer surface.

In another embodiment of the rotary compressor in accordance with the present invention, a roller constitutes a main body of the member of the present invention to define a sliding contact surface at its outer peripheral surface. In the first aspect, a hard carbon film is provided at least on the outer peripheral surface. A mixed layer is formed within the roller adjacent to its outer peripheral surface. In the second aspect, an interlayer is provided on the outer peripheral surface of the roller, and the hard carbon film is provided on the interlayer. A mixed layer is formed within the interlayer adjacent to its outer surface.

In still another embodiment of the rotary compressor in accordance with the present invention, a cylinder constitutes a main body of the member of the present invention to define a sliding contact surface at an inner surface of a cylinder channel. In the first aspect, a hard carbon film is provided on the inner surface of the cylinder channel. A mixed layer is formed within the cylinder wall adjacent to the inner surface of the cylinder channel. In the second aspect, an interlayer is provided on the inner surface of the cylinder channel, and the hard carbon film is provided on the interlayer. A mixed layer is formed within the interlayer adjacent to its outer surface.

The rotary compressor in accordance with a third aspect of the present invention includes a roller, a cylinder and a vane. A hard carbon film is formed on at least a leading end or side portion of the vane, an outer peripheral surface, or an inner surface of a cylinder channel.

In the third aspect, an interlayer may be formed between the hard carbon film and any of the vane, the outer peripheral surface of the roller and the inner surface of the cylinder channel. The types of the interlayer materials employed in the above second aspect may be applicable to the interlayer in the third aspect.

Again, in the third aspect, the hard carbon film may contain hydrogen. If that is the case, it is preferred that the hard carbon film has a hydrogen content gradient in its thickness direction so that a hydrogen content in a thickness portion thereof remoter from its outer surface is higher than in a thickness portion thereof closer to its outer surface.

Again, in the third aspect, the hard carbon film may contain at least one additive element selected from the group consisting of Si, N, Ta, Cr, F and B. It is preferred that the hard carbon film has a content gradient of the additive element in its thickness direction so that a content of the additive element in a thickness portion thereof adjacent to its outer surface is higher than in a thickness portion thereof remoter from its outer surface.

In the present invention, the material types of the main body of the member is not particularly specified and includes Fe-based alloys, cast irons (Mo—Ni—Cr cast irons), steels (high-speed tool steels), aluminum alloys, carbons (aluminum impregnated carbons), ceramics (oxides, nitrides and carbides of Ti, Al, Zr, Si, W, and Mo), Ni alloys, and stainless steels.

In accordance with the present invention, the hard carbon film having a high hardness can be formed on a substrate in a manner to be securedly adhered thereto. Therefore, the member of the present invention exhibits the improved wear resistance and can be steadily used for a prolonged period of time.

The compressors and rotary compressors incorporating such a member produces less sludges even after their prolonged drives so that they can be steadily employed for a prolonged period of time.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic cross-sectional view showing one embodiment in accordance with a third aspect of the present invention;

FIG. **2** is a schematic cross-sectional view showing another embodiment in accordance with the third aspect of the present invention;

FIG. **3** is a schematic cross-sectional view showing still another embodiment in accordance with the third aspect of the present invention;

FIG. **4** is a schematic cross-sectional view of an exemplary ECR plasma CVD apparatus as employed in the embodiments in accordance with the present invention;

FIG. **5** is a graph showing the relation between the film-forming period and the self-bias voltage in the embodiments in accordance with the present invention;

FIGS. **6**(*a*) through **6**(*c*)are graphs showing the relations of the self-bias voltage respectively to the hardness, internal stress and hydrogen content;

FIG. **7** is a graph showing the relation between the film-forming period and the self-bias voltage in the embodiments in accordance with the present invention;

FIG. **8** is a schematic cross-sectional view showing a general structure of a rotary compressor;

FIG. **9** is a schematic cross-sectional view showing one embodiment in accordance with a first aspect of the present invention;

FIG. **10** is an enlarged cross-sectional view showing a vane of the embodiment shown in FIG. **9** and its vicinities;

FIG. **11** is a graph showing the relation between the film-forming period and the self-bias voltage in the embodiments in accordance with the present invention;

FIG. **12** is a schematic cross-sectional view showing another embodiment in accordance with the first aspect of the present invention;

FIG. **13** is a schematic cross-sectional view showing still another embodiment in accordance with the first aspect of the present invention;

FIG. **14** is a schematic cross-sectional view showing one embodiment in accordance with a second aspect of the present invention;

FIG. **15** is an enlarged cross-sectional view showing a vane of the embodiment shown in FIG. **14** and its vicinities;

FIG. **16** are graphs showing composition gradients in a thickness direction of a mixed layer in the embodiments in accordance with the present invention;

FIG. **17** is a schematic cross-sectional view of another exemplary ECR plasma CVD apparatus as employed for the embodiments in accordance with the present invention;

FIG. **18** is a schematic cross-sectional view showing another embodiment in accordance with the second aspect of the present invention;

FIG. **19** is a schematic cross-sectional view showing still another embodiment in accordance with the second aspect of the present invention; and

FIG. **20** is a perspective view of a scroll for use in a scroll type compressor.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. **8** is a schematic cross-sectional view showing a general construction of a rotary compressor.

Referring to FIG. **8**, the rotary compressor includes a closed container **1**, a crank shaft **2** driven by an electric motor (not shown), a roller mounted eccentric to the crank shaft. The roller **3** is made of Mo—Ni—Cr cast iron.

A hollow cylinder **4** of cast iron is disposed to accommodate the roller **3** therein.

The hollow cylinder **4** has a channel **5** within which a vane **6**, as hereinafter described, reciprocates. The vane **6** partitions a space interior of the hollow cylinder **4** into a high-pressure part and a low-pressure part. The vane **6** is made of high-speed tool steel (SKH51).

The vane **6** is urged against the roller **3** by a spring **7**.

An inlet tube **8** is provided to supply a refrigerant carrier into the interior of the hollow cylinder **4**. The refrigerant carrier pressurized and heated within the hollow cylinder **4** is exhausted through an exhaust tube **9**.

The operation of the rotary compressor as constructed in the manner as described above will be now explained.

When the electric motor drives the crank shaft **2**, the roller **3** mounted eccentric to the crank shaft **2** moves circumferentially along an inner surface of the hollow cylinder **4** while rotating. Since the vane **6** is urged against the roller **3** by both a pressurized gas and the spring **7**, the vane **6** is constantly brought into contact with a periphery of the roller **3**. Accordingly, a rotational motion of the roller **3** is translated into a reciprocating motion of the vane **6** within the cylinder channel **5**.

As such a reciprocating motion is continued, the refrigerant carrier is suctioned through the inlet tube **8** into the interior of the hollow cylinder **4** within which it is compressed to increase its temperature and pressure before discharged through the exhaust tube **9** to outside of the rotary compressor.

FIG. **1** is a schematic cross-sectional view of the vane **6** carrying a hard carbon coating film thereon, which can be employed for the rotary compressor of the present invention.

In practicing the present invention, the hard carbon film may be in the form of a diamond thin film, a thin film having a mixed diamond and amorphous carbon structure, or an amorphous carbon thin film.

The interlayer may be formed of Si, Ti, Zr, Ge, Ru, Mo, W, or, oxides, nitrides or carbides thereof.

In the embodiment as shown in FIG. **1**, an interlayer **61** of Si is formed on the vane **6**. A hard carbon film **62** is formed on the interlayer **61** to define an interface therebetween. The hard carbon film **62** has a composition for better adherence onto the vane **6**.

More preferably, the hard carbon film **62** may have a graded composition such that a hydrogen content therein decreases continuously from a portion **62***a* adjacent to the interface to an outer surface of a film layer **62***b*.

Since the hydrogen content is higher toward the portion **62***a* adjacent to the interface, a thickness portion of the hard carbon film **62** adjacent or closer to the interlayer **61** has reduced internal stress and hardness. This serves to prevent the hard carbon film **62** from delaminating from the interlayer **61**.

Although the hydrogen content is above described to be continuously varied in a thickness direction of the hard carbon film **62**, such a hydrogen content gradient may be rendered stepwise by providing a hydrogen-richer layer(s) and a hydrogen-poorer layer(s) in the hard carbon film **62**.

FIG. **2** is a schematic cross-sectional view of the roller **3** carrying thereon a hard carbon film, which can be employed for the rotary compressor of the present invention.

FIG. **2** also shows one applicable form of the hard carbon film in accordance with the present invention.

In the embodiment as shown in FIG. **2**, formed on the roller **3** is an interlayer **31** of Si. A hard carbon film **32** is formed on the Si interlayer **31** to define an interface ther-

ebetween. The hard carbon film **32** has a composition for better adherence to the roller **3**.

More preferably, the hard carbon film **32** may have a graded composition such that a hydrogen content therein decreases continuously from a portion **32***a* adjacent to the interface to a film layer **32***b*.

Since the hydrogen content is higher toward the portion **32***a* adjacent to the interface, a thickness portion of the hard carbon film **32** closer to the interlayer **31** has reduced internal stress and hardness. This serves to prevent the hard carbon film **32** from delaminating from the interlayer **31**.

Although the hydrogen content is above described to be continuously varied in a thickness direction of the hard carbon film **32**, such a hydrogen content gradient may be rendered stepwise by providing a hydrogen-richer layer(s) and a hydrogen-poorer layer(s) in the hard carbon film **32**.

FIG. **3** is an enlarged cross-sectional view of the cylinder channel **5** carrying thereon a hard carbon film, which can be employed for the rotary compressor of the present invention.

FIG. **3** also shows another applicable form of the hard carbon film in accordance with the present invention.

In the embodiment shown in FIG. **3**, formed on an inner surface of a cylinder channel **5** is an interlayer **51** consisting of Si. A hard carbon film **52** is formed on the interlayer **51** to define an interface therebetween. The hard carbon film **52** has a composition for better adherence to the inner surface of the cylinder channel **5**.

More preferably, the hard carbon film **52** may have a graded composition such that a hydrogen content therein is continuously reduced from a portion **52***a* adjacent to the interface to a film layer **52***b*.

Since the hydrogen content is higher toward the portion **52***a* adjacent to the interface, a thickness portion of the hard carbon film **52** closer to the interlayer **51** has reduced internal stress and hardness. This serves to prevent the hard carbon film **52** from delaminating from the interlayer **51**.

Although the hydrogen content is above described to be continuously varied in a thickness direction of the hard carbon film **52**, such a hydrogen content gradient may be rendered stepwise by providing a hydrogen-richer layer(s) and a hydrogen-poorer layer(s) in the hard carbon film **52**.

FIG. **4** is a schematic diagram of an exemplary ECR plasma CVD apparatus which can be employed to form the hard carbon film in the present invention.

Referring to FIG. **4**, disposed interior of a vacuum chamber **108** are a plasma generation chamber **104** and a reaction chamber within which substrates, such as vanes **113** are positioned. One end of a waveguide **102** is connected to the plasma generation chamber **104**. Another end of the waveguide **102** is mounted to a microwave supplying means **101**.

The microwaves generated within the microwave supplying means **101** pass through the waveguide **102** and a microwave inlet window **103** to be guided into the plasma generation chamber **104**.

Connected to the plasma generation chamber **104** is a discharge gas inlet line **105** for introducing a discharge gas such as argon (Ar) into the plasma generation chamber **104**. A plurality of plasma magnetic field generators **106** are mounted circumferentially of the plasma generation chamber **104**.

A drum-shaped vane holder **112** is provided within the reaction chamber in the vacuum chamber **108** so as to be rotatable about an axis which perpendicularly crosses a page surface of the drawing. A motor (not shown) is connected to the vane holder **112**.

A plurality of vanes **113** (twenty four in this embodiment) are arranged circumferentially of the vane holder **112** at regular intervals. A high-frequency power source **110** is connected to the vane holder **112**. A hollow cylindrical shielding cover **114**, made of metal, radially surrounds the vane holder **112** to define therebetween a spacing of about 5 mm. The shielding cover **114** is connected to a grounded electrode. The shielding cover **114** functions to prevent generation of discharges between the vacuum chamber **108** and a vane holder area excluding target film-forming locations thereon, which discharges will be otherwise generated when a radio frequency (RF) voltage is applied to the vane holder **112** for film formation.

The shielding cover **114** has an opening **115**. A plasma from the plasma generation chamber **104** is directed to pass through the opening **115** to impact the vanes **112** mounted on the vane holder **112**. The vacuum chamber **108** is equipped with a reaction gas inlet line **116**. A leading end of the reaction gas inlet line **116** is positioned above the opening **115**.

In the case where the hard carbon film **32** is formed on the peripheral surface of the roller **3**, a drum-shaped holder may not be employed. Then, the roller **3** is connected to the high-frequency power source **110**. The shielding cover **114** is configured to be spaced about 5 mm from the roller **3** and is connected to the grounded electrode.

The aforementioned film forming apparatus may be employed to form the hard carbon film of the embodiment shown in FIG. **1** in the following exemplary procedures.

The vacuum chamber **108** is first evacuated to a pressure of 10^{-5}–10^{-7} Torr., followed by rotation of the vane holder **112** at a speed of about 10 rpm. The Ar gas at 5.7×10^{-4} torr. is then supplied from the discharge gas inlet line **105** while a 2.45 GHz, 100 W microwave is supplied from the microwave supplying means **101**, so that an Ar plasma is generated within the plasma generation chamber **104** to strike a surface of each vane **6**.

Simultaneously with the above, a CH_4 gas at 1.3×10^{-3} Torr. is supplied through the reaction gas inlet line **116** while a 13.56 MHz RF power from the high-frequency power source **116** is supplied to the vane holder **112**. Here, the RF power is supplied to the vane holder **112** in a controlled fashion so that a self-bias voltage generated in each of the vanes **113** is varied through a range from 0 V at the start of the film-forming to −50 V at completion of the film-forming (in 15 minutes after the start), as shown in FIG. **5**.

The hard carbon film of 5000 Å thick was formed on each of the vanes **6** in accordance with the aforementioned procedures.

FIG. **6** are graphs showing the relations of the self-bias voltages produced in the vane holder respectively to the hardnesses, internal stresses and hydrogen contents of the hard carbon films formed at those self-bias voltages.

In operating the aforementioned film-forming apparatus of FIG. **4**, a specific self-bias voltage produced in the vane holder was maintained constant to form a hard carbon film at the specific self-bias voltage. The hard carbon film thus obtained was measured for its properties including hardness, internal stress and hydrogen content. The measured values are given in FIG. **6**.

As can be seen from FIG. **6**, the self-bias voltage of 0 V results in the formation of a hard carbon film having a Vickers hardness of about 800 Hv, an internal stress of about 5 GPa, and a hydrogen content of about 60 atomic percent.

On the other hand, the self-bias voltage of −50 V results in the formation of a hard carbon film having a Vickers

hardness of about 3000 Hv, an internal stress of about 6.5 GPa, and a hydrogen content of about 35 atomic percent.

It is believed that the changes in the respective properties as shown in FIG. **6** have been reflected in a thickness direction of the above embodiment of the hard carbon film formed at varied self-bias voltages from 0 to −50 V.

Therefore, the portion **62***a* of the hard carbon film **62** adjacent to the interface has lower hardness and internal stress to exhibit better adherence to the interlayer, and accordingly to the vane **6**.

On the other hand, the film layer **62***b* has a higher hardness to provide an adequate surface hardness as demanded for the hard carbon films.

The hard carbon film **62** was formed in the same manner as in the above embodiment, with the exception that the self-bias voltage was maintained at 0 V during a first 5-minute period from the start of film formation and at −50 V during a subsequent 10-minute period that completed in 15 minutes from the start, as shown in FIG. **7**. The resulting hard carbon film formed on the vane **6** had a film thickness of 5000 Å and a Vickers hardness of 3000 Hv.

For comparative purposes, a hard carbon film was formed in the same manner as in the above embodiment, with the exception that the self-bias voltage produced in the vane holder was maintained at 0 V during the film formation. The resulting hard carbon film formed on the vane **6** had a film thickness of 5000 Å and a Vickers hardness of 800 Hv.

The hard carbon film was tested for adherence. In evaluating the adherence, a constant load (1 kg) indentation test was conducted using a Vickers penetrator. For evaluating the adherence of differently formed hard carbon films, fifty samples were prepared for each and the number of samples which showed the delamination of the hard carbon film **62** from the vane **6** was counted as indicating the level of the adherence thereof. Those hard carbon films subjected to such an evaluation included a hard carbon film which was formed at the varied self-bias voltages from 0 V to −50 V upon the Si interlayer **61** (100 Å thick) previously formed upon the vane **6**, another hard carbon film which omitted the Si interlayer **61** to form directly upon the vane **6** at a constant self-bias voltage of −50 V maintained after the lapse of five minutes from the start of film formation till the completion of film formation, and another hard carbon film which was formed on the Si interlayer **61** at a constant self-bias voltage of −50 V maintained after the lapse of five minutes from the start of film formation till the completion of film formation. The evaluation results are shown in Table 1.

TABLE 1

Si Interlayer	Self-Bias Voltage (V)	Number of Samples Experienced Delamination
Absent	−50	45
Present	−50	5
	0—50	0

As can be seen from Table 1, in the case where the Si interlayer **61** was not formed on the vane **6**, i.e., the hard carbon film **62** was directly formed on the vane **6**, forty five samples thereof were found to delaminate from the vane **6** even though formed at the self-bias voltage of −50 V. On the other hand, in the case where the Si interlayer **61** was formed on the vane **6**, i.e., the hard carbon film **62** was formed on the interlayer **61** at the constant self-bias voltage of −50 V, only five samples thereof were observed to delaminate from the interlayer **61**.

Furthermore, in the case where the Si interlayer **61** was formed on the vane **6**, i.e., the hard carbon film **62** was formed on the Si interlayer **61** at the varied self-bias voltages from 0 V to −50 V, no sample thereof showed delamination.

The above results demonstrate that the hard carbon film for use in the present invention has improved hardness and adherence sufficient to impart a wear-resistance to sliding contact surfaces of various member such as of the vane **6**, roller **3** and cylinder channel **5**. Such a hard carbon film coating serves to reduce sludge production at the sliding contact surfaces of those members.

In the above embodiments, the ECR plasma CVD apparatus is employed to form the hard carbon film. However, it is to be understood that this is not intended to exclude the use of the other suitable techniques for the film formation.

As will be appreciated from the above descriptions, the present invention provides a vane, roller or cylinder channel on which a hard carbon film is formed to impart thereto adequate hardness and chemical stability. Since the hard carbon film can be well adhered to the vane, roller or cylinder channel, a rotary compressor incorporating such components can be operated for a prolonged period of time without producing an appreciable amount of sludge. This prevents the occurrence of its blocking the supply of refrigerant carrier through a capillary tube and performs a protective effect by which a critical damage to the rotary compressor can be avoided.

FIG. **9** is schematic perspective view showing one embodiment in accordance with a first aspect of the present invention. A hard carbon film **64** is formed on a main body of a member in accordance with the present invention, i.e. a vane **6** to define an interface therebetween. A mixed layer **63** is formed in a thickness region of the vane **6** adjacent to the interface.

FIG. **10** is an enlarged schematic cross-sectional view showing the vane **6** of FIG. **9** and its vicinities. As illustrated in FIG. **10**, the mixed layer **63** is formed in the thickness region of the vane **6** adjacent to the interface. The mixed layer **63** is formed of carbon and an constituent element of the vane **6**, e.g. Fe. A carbon content in a thickness portion **63***b* of the mixed layer **63** closer to the interface is made higher than in a thickness portion **63***a* of the mixed layer **63** remoter from the interface to define a carbon content gradient in a thickness direction of the mixed layer **63**. Such a mixed layer **63** can be formed by introducing carbon into the thickness region of the vane **6** adjacent to the interface. The introduction of carbon can be accomplished, for example, by operating the above-described ECR plasma CVD apparatus to cause the vane **6** to produce a negative self-bias voltage at an early stage of film formation.

The hard carbon film **64**, such as a diamond-like carbon film is formed on the mixed layer **63**. Preferably, the hard carbon film has a hydrogen content gradient in its thickness direction so that a hydrogen content in a thickness portion **64***b* thereof remoter from an outer surface of the hard carbon film is higher than in a thickness portion **64***a* thereof closer to the outer surface of the hard carbon film.

The thickness of the mixed layer **63** is preferably not less than 5 Å, more preferably in the range of 10–200 Å.

The apparatus of FIG. **4** was employed to form a hard carbon film. The self-bias voltage produced in the vane was maintained at −50 V during a first one-minute period from the start of the film formation. As shown in FIG. **11**, the self-bias voltage was subsequently dropped to 0 V and varied immediately thereafter such that it increased gradually from 0 V to reach −50 V at the completion of film

formation. During the first one-minute period when the self-bias voltage was maintained at −50 V, the mixed layer is formed within the vane adjacent to an outer surface of the vane. As a result, the hard carbon film was formed on the vane which had a thickness of 5000 Å and a Vickers hardness of 3000 Hv.

The hard carbon film thus formed was subjected to a scratch test for adherence evaluation. A diamond stylus was employed to conduct the test at a scratching speed of 100 mm/min. The maximum load was 500 g. Fifty samples of hard carbon film were tested, and the number of samples which showed delamination was counted as being indicative of a level of adherence of the hard carbon film. No sample was observed to experience delamination.

For comparative purposes, a RF power is applied so that the self-bias voltage produced in the vane was varied from 0 V at the start of film formation to −50 V at the completion of film formation when 15 minutes passed from the start, as shown in FIG. **5**. The comparative hard carbon film thus formed revealed a thickness of 5000 Å and a Vickers hardness of 3000 Hv. The number of samples which experienced delamination was ten out of fifty.

As will be recognized from the above results, the adherence of the hard carbon film to a substrate, such as the vane, can be enhanced by forming an effective thickness of mixed layer in the surface layer of the substrate.

FIG. **12** is a schematic cross-sectional view showing another embodiment in accordance with the first aspect of the present invention. A mixed layer **33** is formed within a roller **3** adjacent to an outer surface of the roller **3**. Again, a carbon content in a thickness portion of the mixed layer **33** closer to its outer surface is higher than in a thickness portion remoter from its outer surface to define a carbon content gradient in the thickness direction of the mixed layer **33**, as analogous to the embodiment shown in FIG. **11**. The mixed layer **33** can be formed in the same manner as in the embodiment of FIG. **11**. A hard carbon film **34** is formed upon the mixed layer **33**.

The formation of the mixed layer **33** adjacent to an outer surface of the roller **3** results in improved adherence of the hard carbon film **34** to the roller **3**.

FIG. **13** is a schematic cross-sectional view showing still another embodiment in accordance with the first aspect of the present invention. A mixed layer **53** is formed in an inner wall of a cylinder channel **5** adjacent to an inner surface of the cylinder channel. As analogous to the embodiment shown in FIG. **11**, the mixed layer **53** has a carbon content gradient in its thickness direction such that a carbon content in a thickness portion of the mixed layer **53** closer to its outer surface is higher than in a thickness portion of the mixed layer **53** remoter from its outer surface. The mixed layer **53** can be formed in the same manner as in the embodiment of FIG. **11**. A hard carbon film **54** is formed on the mixed layer **53**.

The formation of the mixed layer **53** adjacent to the inner surface of the cylinder channel **5** results in improved adherence of the hard carbon film **34** to the inner surface of the cylinder channel **5**.

FIG. **14** is a partly sectioned, schematic perspective view showing an embodiment in accordance with the second aspect of the present invention. Formed upon a vane **6** is an interlayer **65**. A mixed layer **66** is formed within the interlayer **66** adjacent to an outer surface of the interlayer **66**. The mixed layer **66** is formed of carbon and a constituent element of the interlayer **65**. A hard carbon film **67** is formed upon the interlayer **65**.

FIG. **15** is an enlarged schematic cross-sectional view showing the vane **6** of FIG. **14** and its vicinities. As illustrated in FIG. **15**, the mixed layer **66** has a carbon content gradient in its thickness direction such that a carbon content in a thickness portion **66***b* of the mixed layer **63** closer to the outer surface of the mixed layer **66** is higher than in a thickness portion **66***a* of the mixed layer **63** remoter from the outer surface of the mixed layer **63**. Such a mixed layer **66** can be formed in the same manner as the mixed layer **63** of FIG. **10** is formed, i.e., by introducing carbon into the thickness region of the vane **6** adjacent to the outer surface of the interlayer **65**. The introduction of carbon can be accomplished, for example, by operating the above-described ECR plasma CVD apparatus to cause a substrate such as the vane **6** to produce a negative self-bias voltage at an early stage of film formation.

A hard carbon film **67** is formed on the mixed layer **66**. The presence of the mixed layer **66** contributes to the improved adherence of the hard carbon film **67** to the interlayer **65**.

In this second aspect, if the mixed layer is desired to be made thicker than the interlayer, the mixed layer may also be formed in the underlying substrate adjacent to its surface so that it extends through the interlayer into the substrate.

FIG. **16** is a graph showing a composition gradient in a thickness direction of the mixed layer formed within the interlayer. In this particular embodiment, the interlayer consists of Si. A RF power was applied to a substrate holder so that the self-bias voltage produced in a substrate was set at −50 V in an early stage of film formation. Otherwise analogously to the manner as employed in the above embodiment, a hard carbon film was formed on the Si interlayer.

As shown in FIG. **16**, the carbon content reaches to zero at a depth of 50 Å from a surface of the mixed layer. The thickness of the mixed layer is about 50 Å. The mixed layer exhibits a maximum carbon content of about 70 atomic percent at a site A which is located at a depth of about 35% of a whole thickness of the mixed layer from the outer surface of the mixed layer. As also shown in FIG. **16**, the mixed layer has a mixed layer portion within which a carbon content in a thickness portion closer to the mixed layer surface is higher than in a thickness portion remoter from the mixed layer surface to define a carbon content gradient B. The mixed layer has another mixed layer portion extending from its outer surface to the site A within which a carbon content in a thickness portion closer to the outer surface of the mixed layer is slightly decreasing to define a carbon content gradient A. The improved adhesion of the hard carbon film to the mixed layer is assured by establishing such a carbon content gradient within the mixed layer that a carbon content in a thickness portion adjacent or closer to the outer surface of the mixed layer is higher than in a thickness portion opposite to or remoter from the outer surface of the mixed layer.

The thickness of the mixed layer can be controlled such as by varying the self-bias voltage produced in the substrate. For example, in case of the Si interlayer, if the self-bias voltage across the substrate is controlled at −1 KV in an early stage of film formation, the mixed layer can be formed to a thickness of about 130 Å.

A Si interlayer was formed on a vane to a thickness of 100 Å. A hard carbon film was subsequently formed on the Si interlayer. A self-bias voltage was varied during film formation in the manner as illustrated in FIG. **11**. The resulting hard carbon film had a thickness of 5000 Å and a Vickers

hardness of 3000 Hv. The hard carbon films formed were subjected to a scratch test for adherence evaluation. No sample thereof showed delamination.

Next, a hard carbon film was formed which contained an additive element. Such an hard carbon film containing the additive element was formed through an apparatus shown in FIG. **17**. Referring to FIG. **17**, in addition to having an opening **115** in the shield cover **114**, the apparatus has a second opening **117** spaced from the opening **115**. A target **118** is disposed to face toward the second opening **117**. An ion beam gun **119** is disposed in such a location that the target **118** can be irradiated with an ion beam from the ion beam gun **119**. The other constructions are analogous to respective ones of the apparatus of FIG. **4**.

The target materials included Si, Ta, Cr and B. The hard carbon films containing any of those additive elements were formed using the apparatus shown in FIG. **17**. The vane holder **112** was rotated during film formation, so that the carbon and additive element were deposited on each vane **113** through the opening **115** and the second opening **117**, respectively. As a result, the hard carbon film containing the additive element was formed on each vane **113**. The vane **113** had been precoated with an interlayer (100 Å thick) prior to film formation.

The target **118** was not employed when introducing N or F into a hard carbon film. Instead, a N_2 or CF_4 gas was introduced into a film formation atmosphere. More specifically, the CH_4 gas and a N_2 or CF_4 gas were supplied at respective partial pressures of 1.3×10^{-3} and 1.0×10^{-3} Torr.

The resulting hard carbon films were transferred to a surface characteristic tester for measurement of their friction coefficients and depths of wear. The friction coefficient was measured for Si, Ta and F while the depth of wear was measured for N, Cr and B. For comparative purposes, vanes carrying thereon neither the interlayer nor the hard carbon film, and vanes coated with the hard carbon film not containing the additive element were respectively prepared for measurement of their friction coefficients and depths of wear. For the depth of wear, a relative evaluation was made with respect to the hard carbon film not containing the additive element. The results are given in the following Table 2. For measurement, an aluminum ball indenter was employed which slidingly reciprocated two thousand times.

TABLE 2

Additive Element		Friction Coefficient	Wear Depth (Relative Value)
Type	Si	0.1	—
	Ta	0.13	—
	F	0.12	—
	N	—	0.6
	Cr	—	0.8
	B	—	0.7
	None	0.18	1
W/O Hard Carbon Film and Interlayer		0.5	4

As apparent from Table 2, the inclusion of additive elements in the resulting hard carbon films impart thereto improved friction coefficients and wear depths.

The content of the additive element may be made higher in a thickness portion of the hard carbon film closer to its outer surface than in a thickness portion thereof remoter from its outer surface. The provision of such a content gradient of the additive element improves the adherence of the resulting hard carbon film.

FIG. **18** is a partly cutaway schematic cross-sectional view showing another embodiment in accordance with the second aspect of the present invention. An interlayer **35** is formed on a roller **3**. A mixed layer **36** is formed within the interlayer **35** adjacent to an outer surface of the interlayer **35**. A hard carbon film **37** is formed on the interlayer **35**. The mixed layer **36** can be formed in the interlayer **35** analogously to the embodiment of FIG. **14**. The formation of the mixed layer **36** in the interlayer **35** enhances its adhesion to the hard carbon film **37**.

FIG. **19** is a partly cutaway schematic cross-sectional view showing still another embodiment in accordance with the second aspect of the present invention. An interlayer **55** is formed on an inner surface of a cylinder channel **5**. A mixed layer **56** is formed within the interlayer **55** adjacent to an outer surface of the interlayer **55**. A hard carbon film **57** is formed on the interlayer **35**. The mixed layer **56** can be formed in the interlayer **35** analogously to the embodiment of FIG. **14**. The formation of the mixed layer **56** in the interlayer **55** enhances its adhesion to the hard carbon film **57**.

In the above embodiments, the series of interlayer and hard carbon film was formed on an extensive surface area of the vane. However, they may be formed only on the surface area of a leading end of the vane.

Although the rotary compressor components were exemplarily used in the above embodiments to explain the members having a sliding contact surface in accordance with the present invention, the present invention is not limited to those rotary compressor components. The present invention is applicable to a cylinder or piston of a reciprocating compressor, further to an outer surface of an **0**-ring mounted to the piston, for example.

FIG. **20** is a perspective view of a scroll for use in a scroll compressor. The present invention is applicable to such a scroll **70**. A lapped portion **71** and a mirror plate **70** of the scroll **70** provide sliding contact surfaces respectively.

Also, the member having a sliding contact surface in accordance with the present invention is not limited to compressor components, and is applicable to a variety of members which includes a sliding contact surface. For example, the present invention may be applied to such a member as an inner or outer blade edge of an electric shaver. Furthermore, the present invention is applicable to a sliding portion of a thin layer magnetic head for use in hard disk drives, VTR cylinders, and outer surfaces of optical magnetic disks.

What is claimed is:

1. A member comprising:

a main body having a sliding contact surface;

a hard carbon film provided on said sliding contact surface of the main body, wherein said hard carbon film comprises a diamond thin film, a film having a mixed diamond and amorphous structure or an amorphous carbon thin film;

a mixed layer formed within a thickness region of said main body adjacent to said sliding contact surface thereof and containing carbon and a constituent element of said thickness region of the main body; and

said mixed layer having a carbon content gradient in its thickness direction so that a carbon content in a thickness portion thereof closer to an outer surface of the mixed layer is higher than in a thickness portion thereof remoter from the outer surface of the mixed layer, wherein said mixed layer is formed by introducing the carbon into said thickness region of the main body adjacent to the sliding contact surface thereof.

2. The member of claim 1, wherein a thickness of said mixed layer is at least 5 Å.

3. The member of claim 1, wherein said hard carbon film has a hydrogen content gradient in its thickness direction so that a hydrogen content in a thickness portion thereof remoter from an outer surface of the hard carbon film is higher than in a thickness portion thereof closer to the outer surface of the hard carbon film.

4. The member of claim 1, wherein said mixed layer includes a concentrated portion having a maximum carbon content of at least 20 atomic percent.

5. The member of claim 4, wherein said concentrated portion is present within a thickness region which covers 50% or less of a whole thickness of the mixed layer from the outer surface of mixed layer.

6. The member of claim 1, wherein said hard carbon film contains at least one additive element selected from the group consisting of Si, N, Ta, Cr, F and B.

7. The member of claim 6, wherein said hard carbon film has a content gradient of said additive element in its thickness direction so that an additive element content in a thickness portion thereof closer to the outer surface of the hard carbon film is higher than in a thickness portion thereof remoter from the outer surface of the hard carbon film.

8. A compressor incorporating the member of claim 1.

9. A rotary compressor comprising:

a roller mounted eccentric to a rotatable crank shaft and having an outer periphery;

a hollow cylinder for accommodating said roller therein, said hollow cylinder having an inner surface in sliding contact with said outer periphery of the roller; and

a vane received in a channel provided on said inner surface of the cylinder and having a leading end in sliding contact with said outer periphery of the roller,

wherein said vane is said main body of the member of claim 1 and at least said leading end or a side portion of the vane constitutes said sliding contact surface.

10. A rotary compressor comprising:

a roller mounted eccentric to a rotatable crank shaft and having an outer periphery;

a hollow cylinder for accommodating said roller therein, said hollow cylinder having an inner surface in sliding contact with said outer periphery of the roller; and

a vane received in a channel provided on said inner surface of the cylinder and having a leading end in sliding contact with said outer periphery of the roller,

wherein said roller is said main body of the member of claim 1 and said outer periphery of the roller constitutes said sliding contact surface.

11. A rotary compressor comprising:

a roller mounted eccentric to a rotatable crank shaft and having an outer periphery;

a hollow cylinder for accommodating said roller therein, said hollow cylinder having an inner surface in sliding contact with said outer periphery of the roller; and

a vane received in a channel provided on said inner surface of the cylinder and having a leading end in sliding contact with said outer periphery of the roller,

wherein said hollow cylinder is said main body of the member of claim 1 and said inner surface of the hollow cylinder constitutes said sliding contact surface.

* * * * *

Exhibit B

US006354008B1

(12) **United States Patent**
Domoto et al.

(10) **Patent No.: US 6,354,008 B1**
(45) **Date of Patent: *Mar. 12, 2002**

(54) **SLIDING MEMBER, INNER AND OUTER BLADES OF AN ELECTRIC SHAVER AND FILM-FORMING METHOD**

(75) Inventors: **Yoichi Domoto**, Ikoma; **Hitoshi Hirano**, Nishinomiya; **Keiichi Kuramoto**, Kadoma, all of (JP)

(73) Assignee: **Sanyo Electric Co., Inc.**, Osaka (JP)

(*) Notice: This patent issued on a continued prosecution application filed under 37 CFR 1.53(d), and is subject to the twenty year patent term provisions of 35 U.S.C. 154(a)(2).

Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/156,825**

(22) Filed: **Sep. 21, 1998**

(30) **Foreign Application Priority Data**

Sep. 22, 1997	(JP)	9-256986
Sep. 25, 1997	(JP)	9-259834
Aug. 25, 1998	(JP)	10-238173

(51) **Int. Cl.**[7] **B26B 19/04**
(52) **U.S. Cl.** **30/346.53**; 30/346.51
(58) **Field of Search** .... 30/346.51, 346.54, 30/346.58, 350, 346.53; 76/115, 116, 104.1, DIG. 8

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Primary Examiner—Hwei-Siu Payer
(74) *Attorney, Agent, or Firm*—Arent Fox Kintner Plotkin & Kahn, PLLC

(57) **ABSTRACT**

A sliding member having a sliding surface for sliding contact with a cooperative member is disclosed. A protective film is deposited not only on the sliding surface but also a surface region immediately adjacent the sliding surface such that a ratio d1/d2 is controlled to be 1 or greater, where d1 is a thickness of the protective film on the sliding surface and d2 is a thickness of the protective film on the surface region immediately adjacent the sliding surface. Alternatively, the protective film is deposited at least on the sliding surface such that the protective film is varied in thickness to define an irregular top surface.

5 Claims, 25 Drawing Sheets

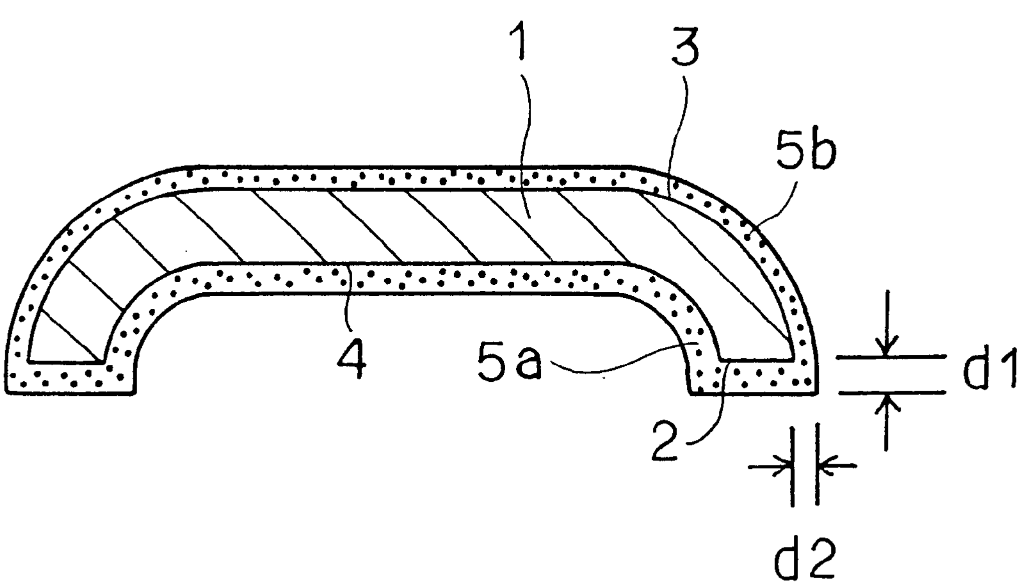


FIG. 1

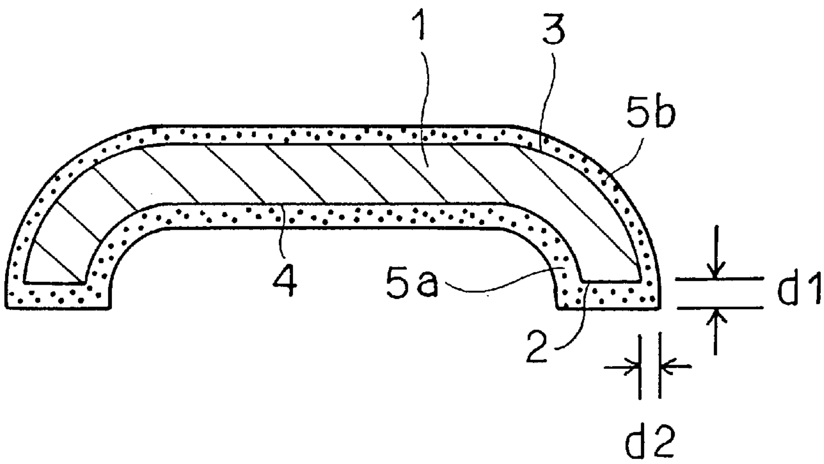


FIG. 2

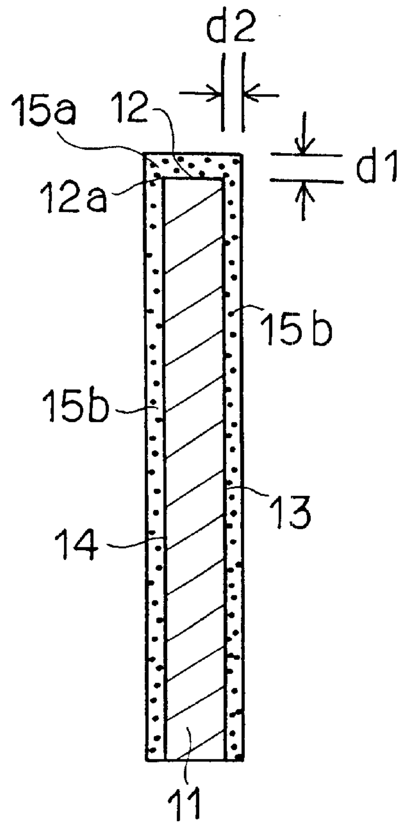


FIG. 3

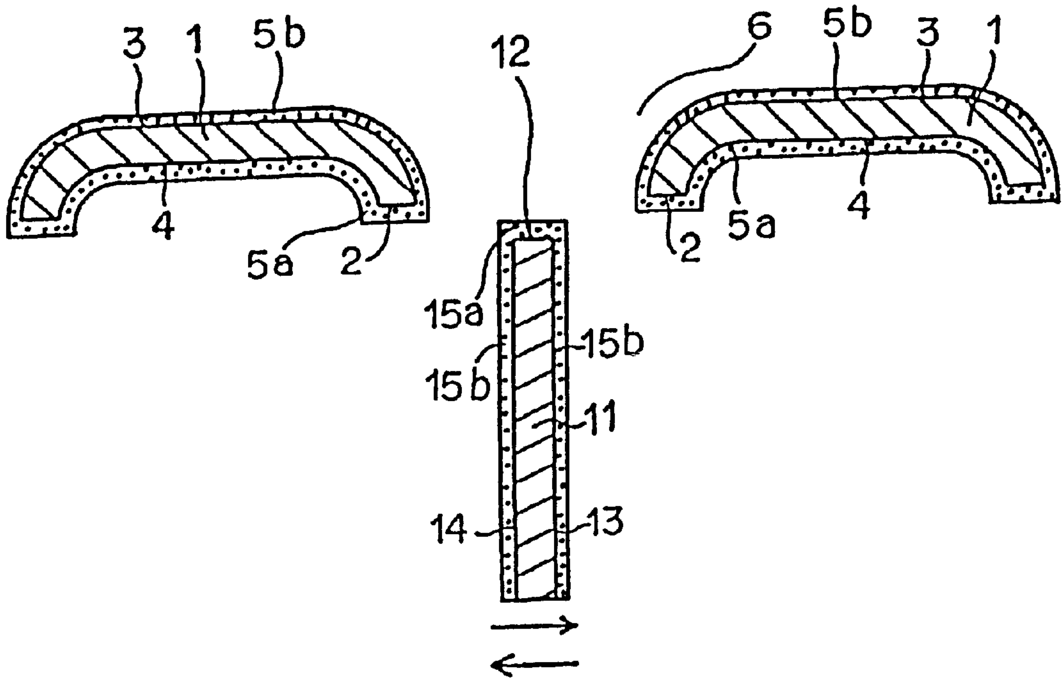


FIG. 4

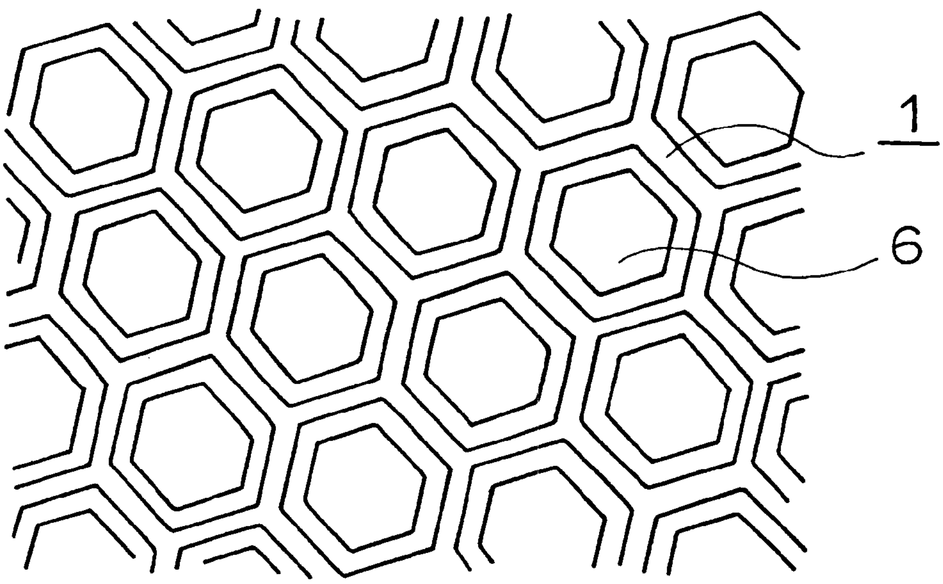


FIG. 5

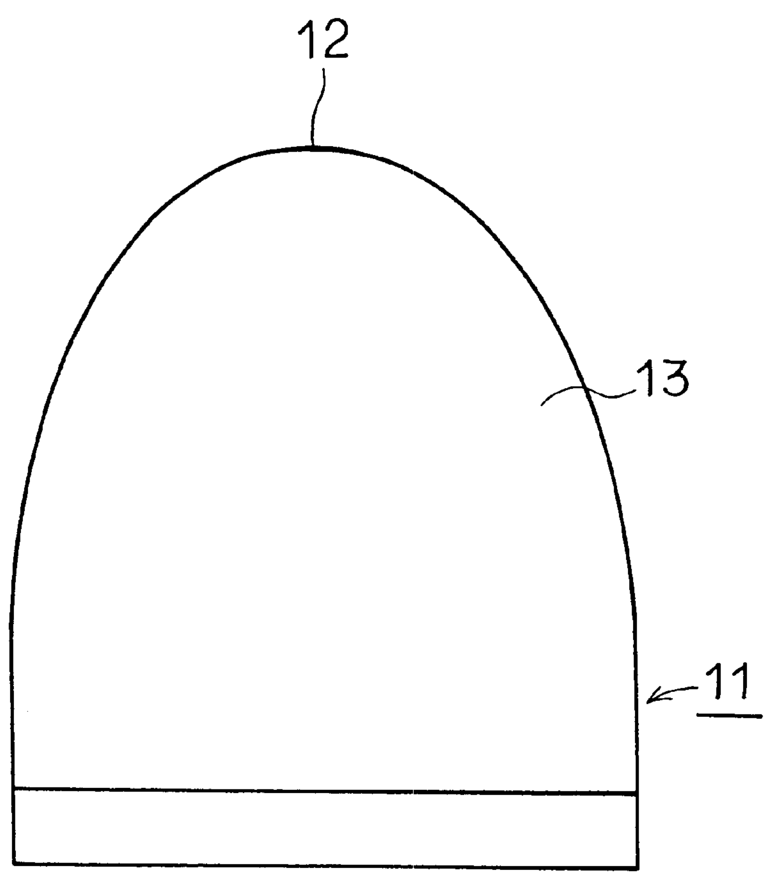


FIG. 6

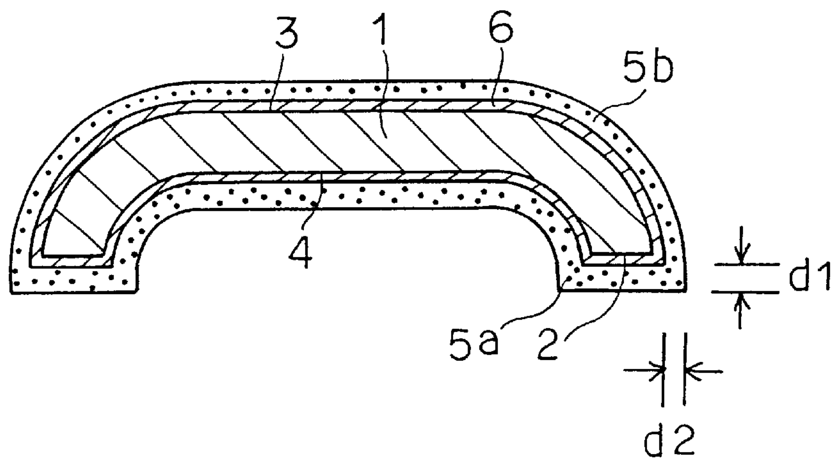


FIG. 7

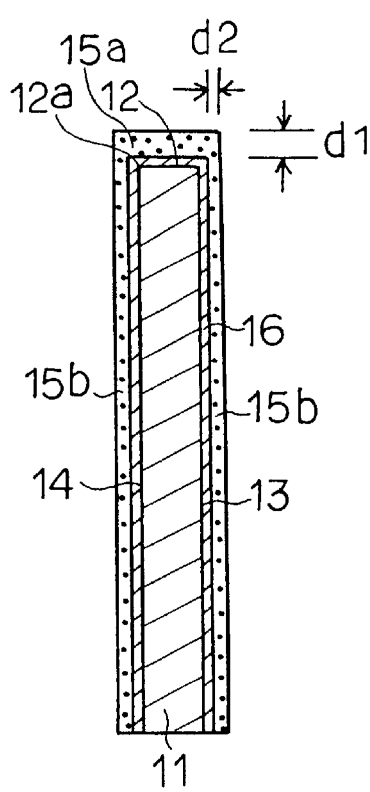


FIG. 8

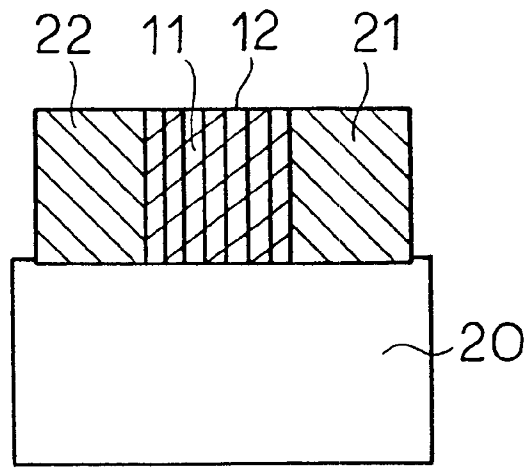


FIG. 9

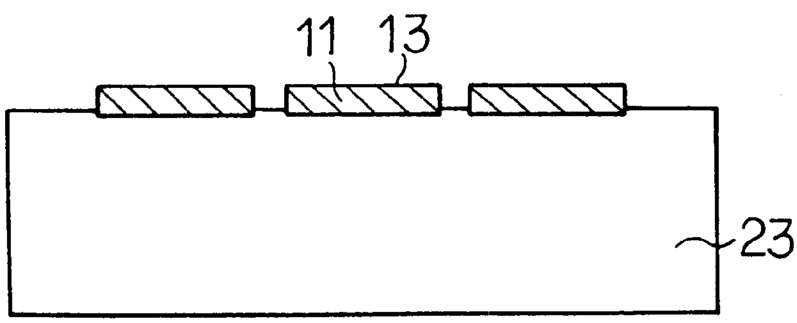


FIG. 10

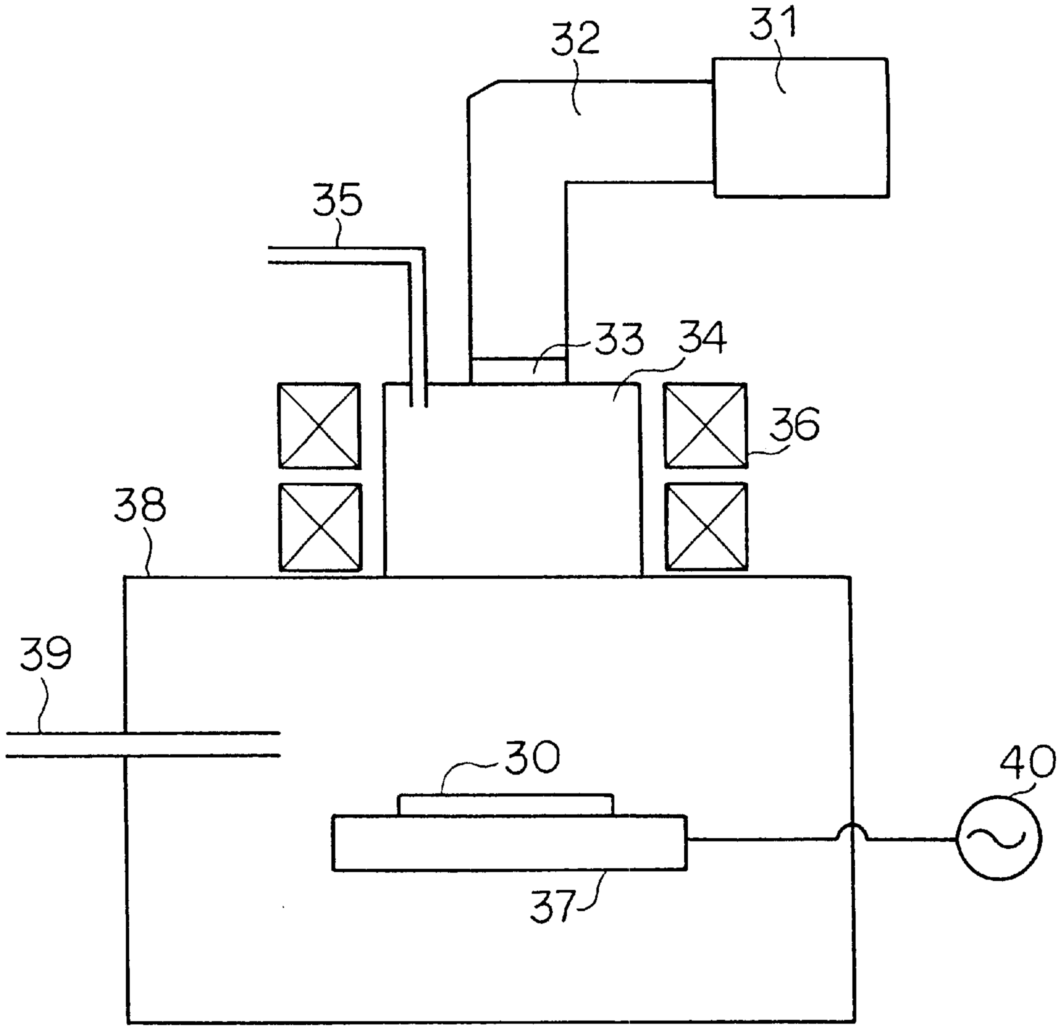


FIG. 11

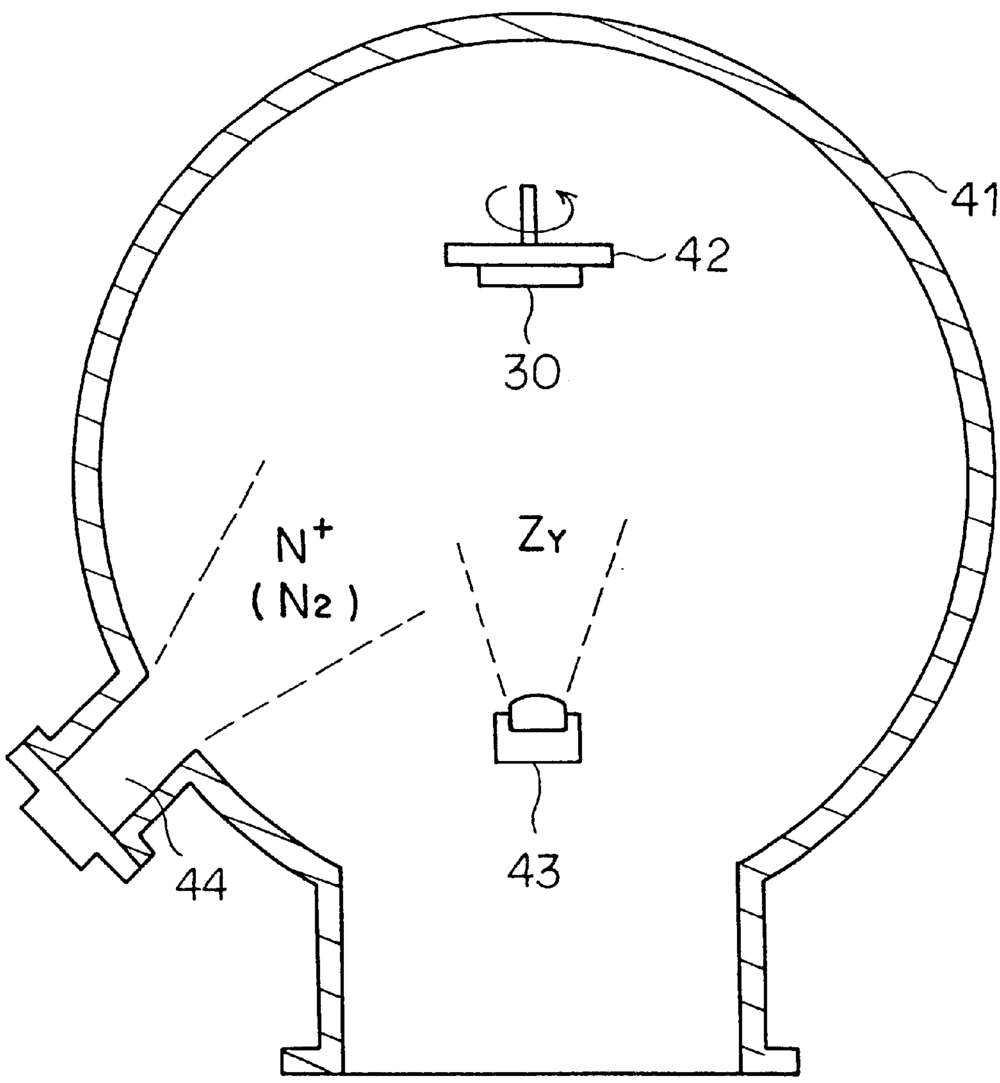
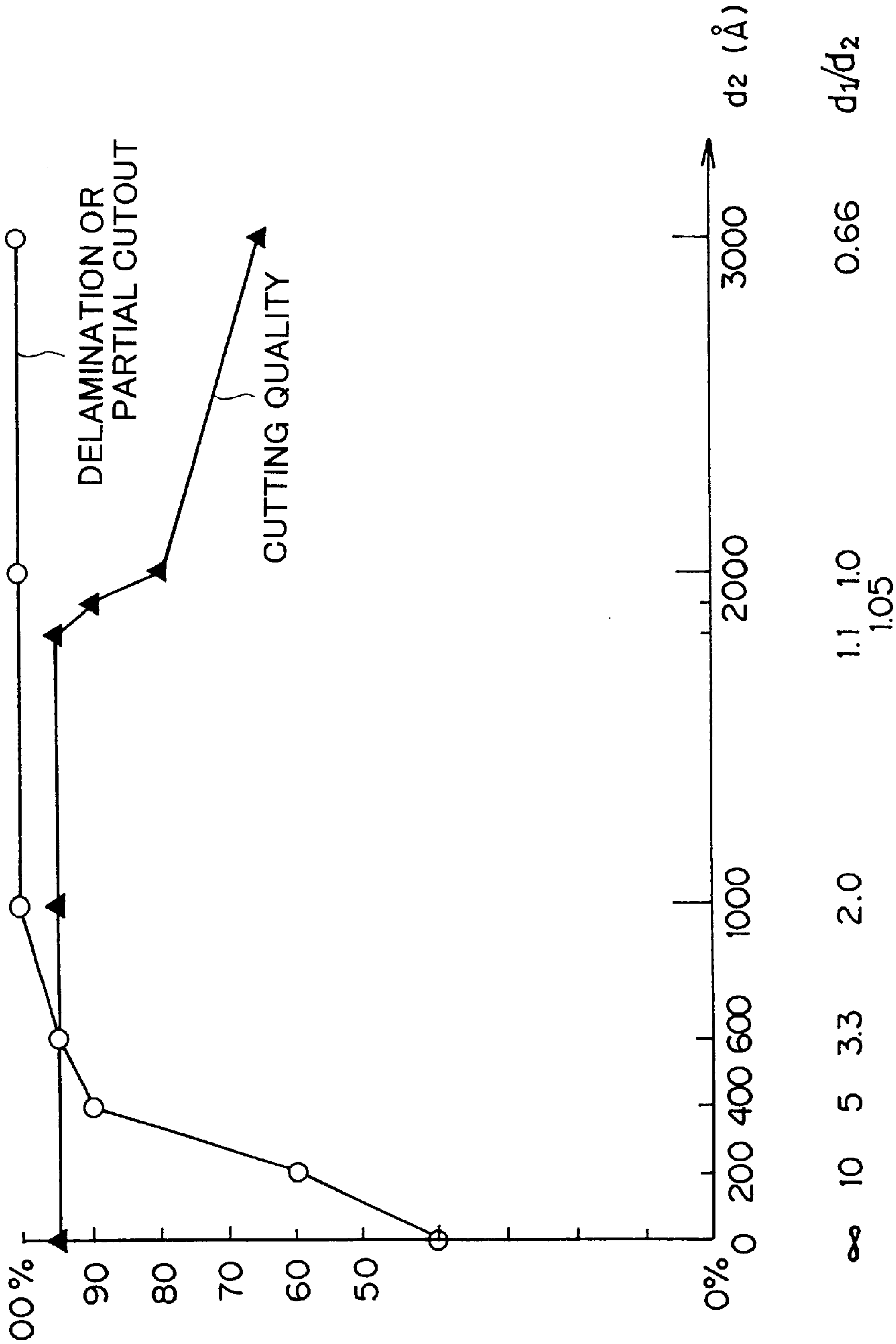


FIG. 12



DELAMINATION OR PARTIAL CUTOUT
CUTTING QUALITY
100 %
90
80
70
60
50
0%
0
200
400
600
1000
2000
3000
d2 (Å)
∞
10
5
3.3
2.0
1.1
1.05
1.0
0.66
d1/d2

FIG. 13

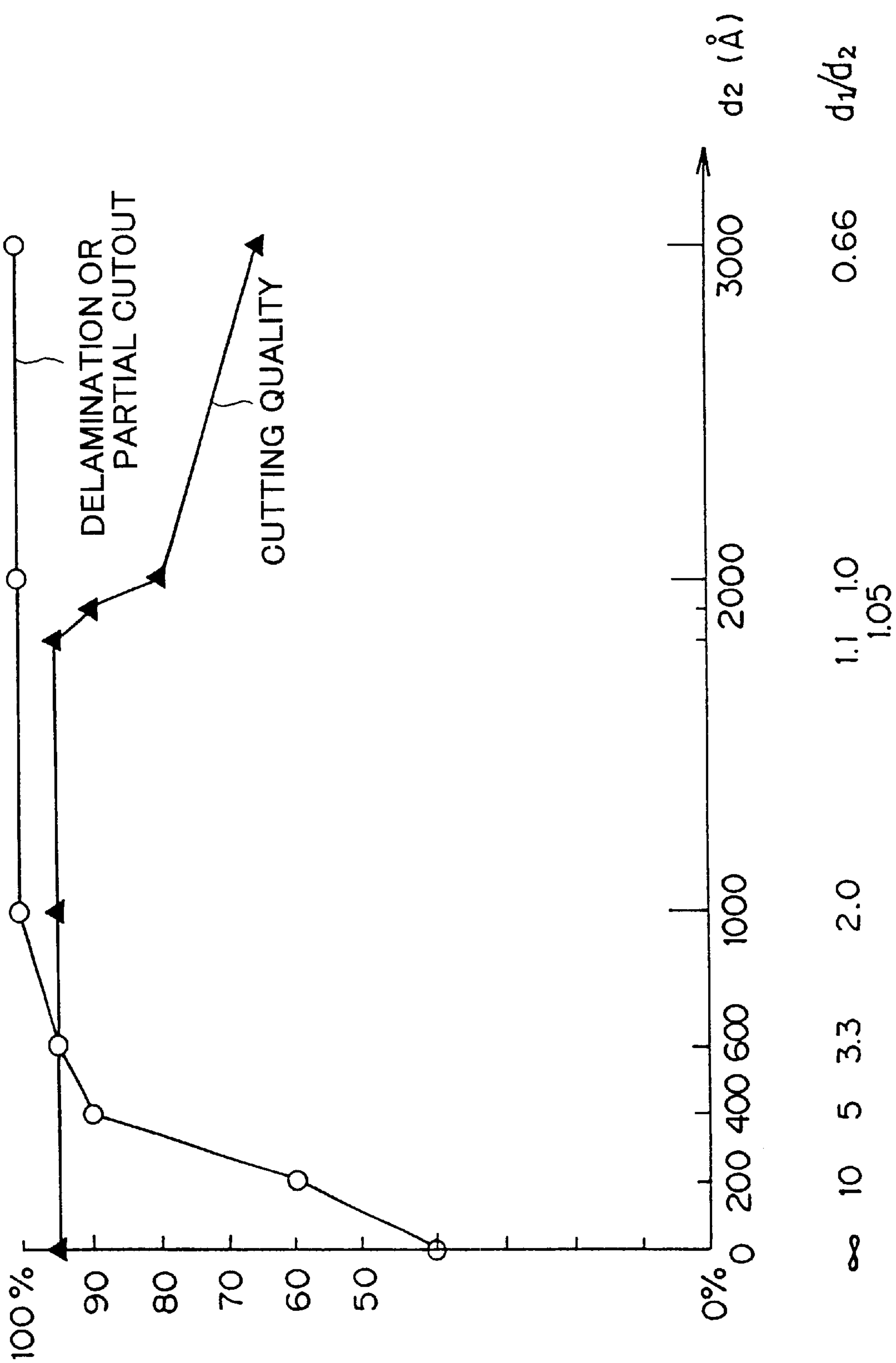
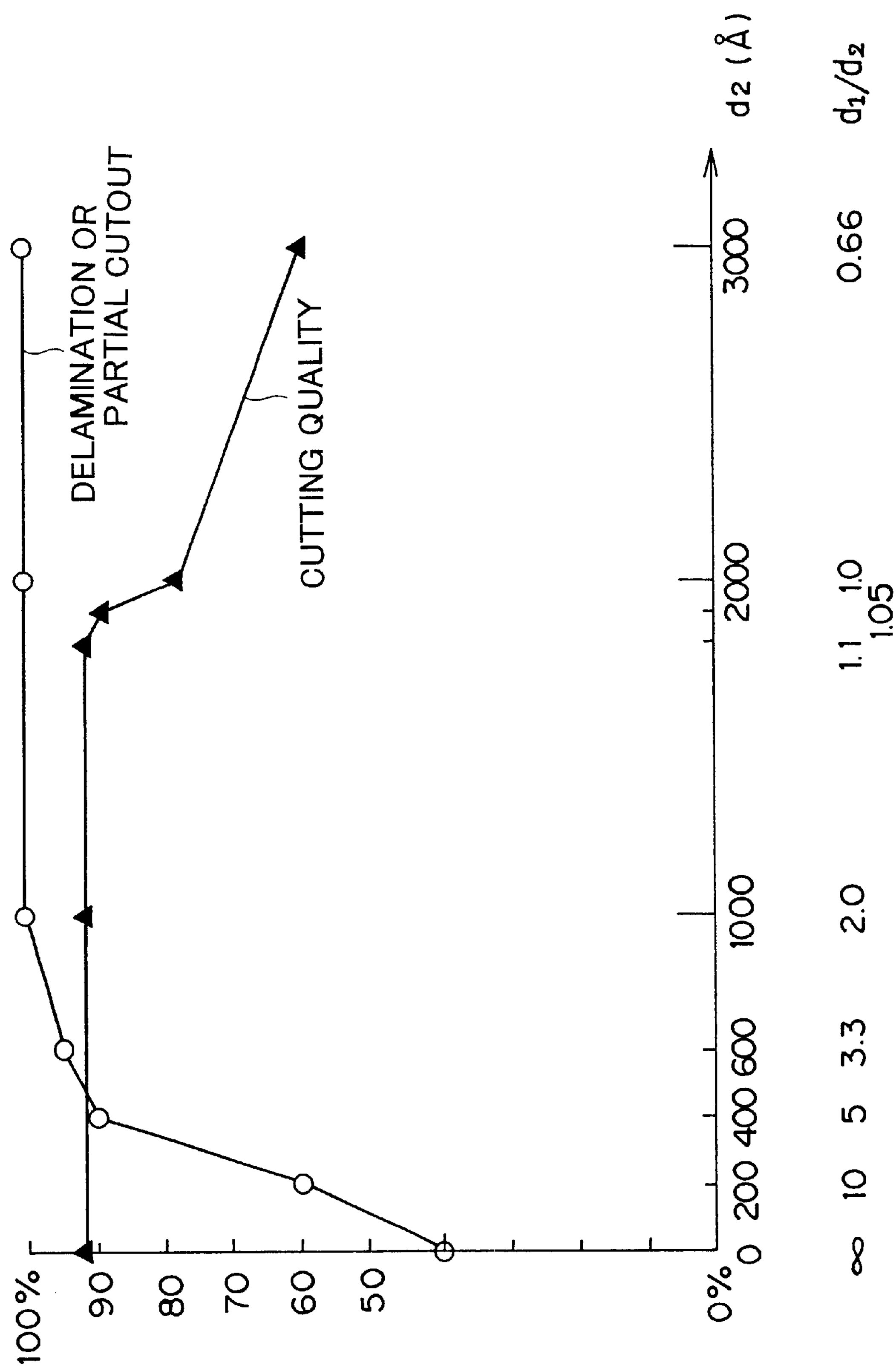

DELAMINATION OR
PARTIAL CUTOUT
CUTTING QUALITY
100 %
90
80
70
60
50
0%
0
200
400
600
1000
2000
3000
d_2 (Å)
∞
10
5
3.3
2.0
1.1
1.05
1.0
0.66
d_1/d_2

FIG. 14



DELAMINATION OR PARTIAL CUTOUT
CUTTING QUALITY
100%
90
80
70
60
50
0%
d2 (Å)
0
200
400
600
1000
2000
3000
d1/d2
∞
10
5
3.3
2.0
1.1
1.05
1.0
0.66

FIG. 15

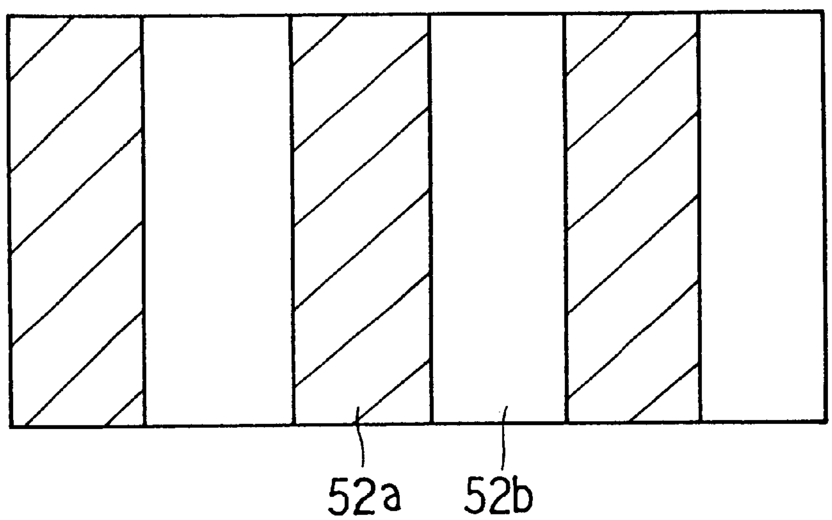


FIG. 16

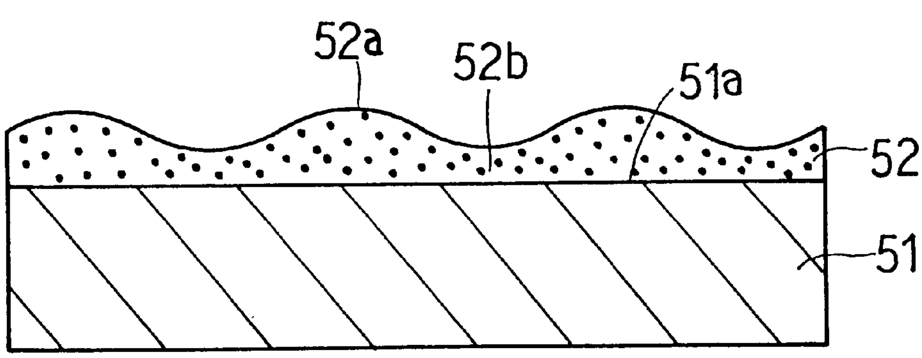


FIG. 17

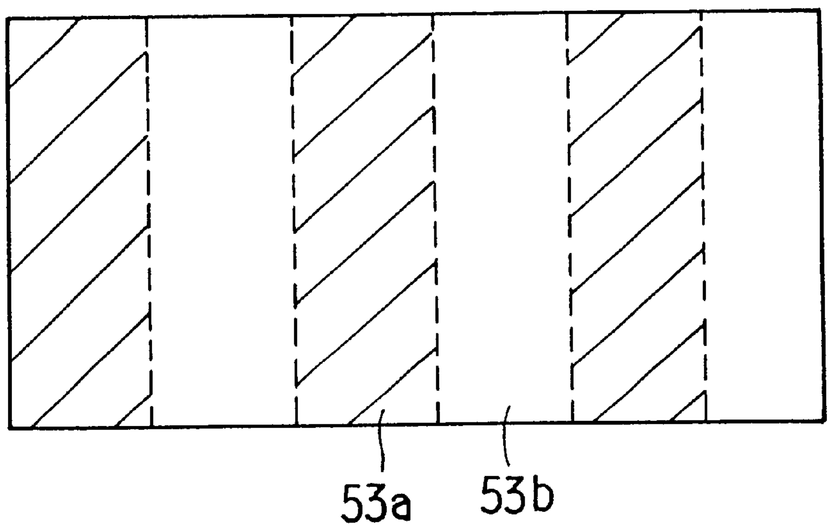


FIG. 18

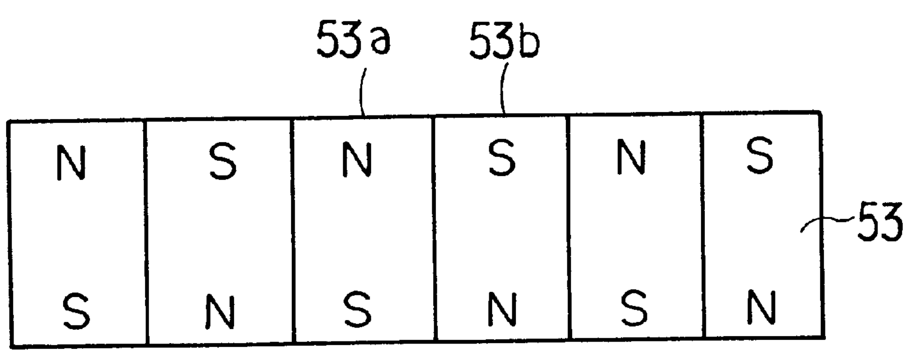


FIG. 19

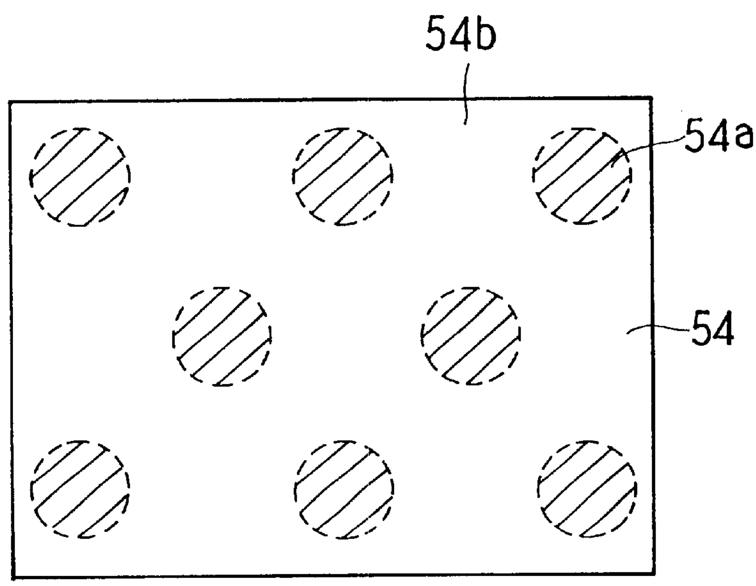


FIG. 20

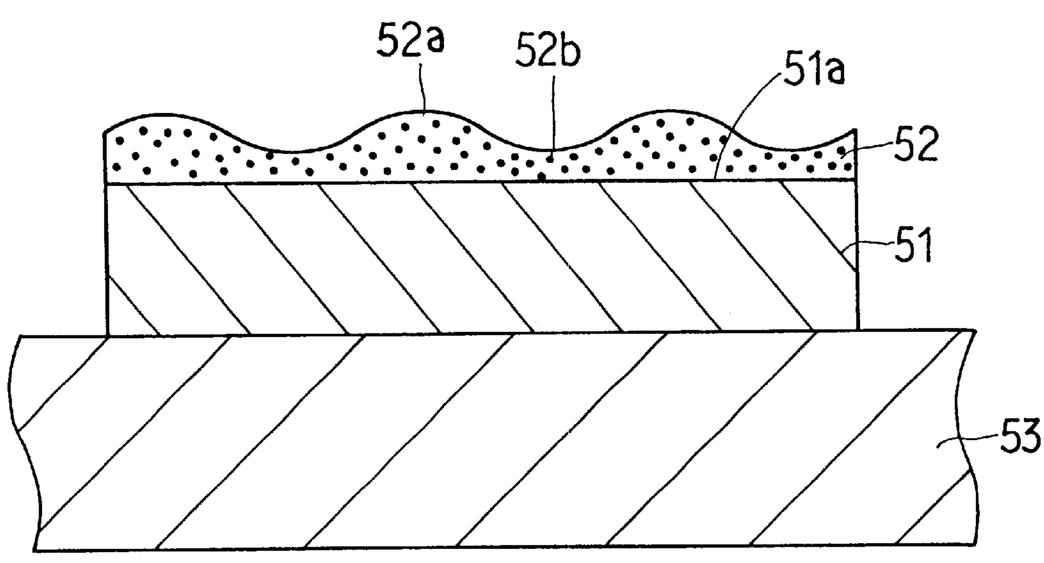


FIG. 21

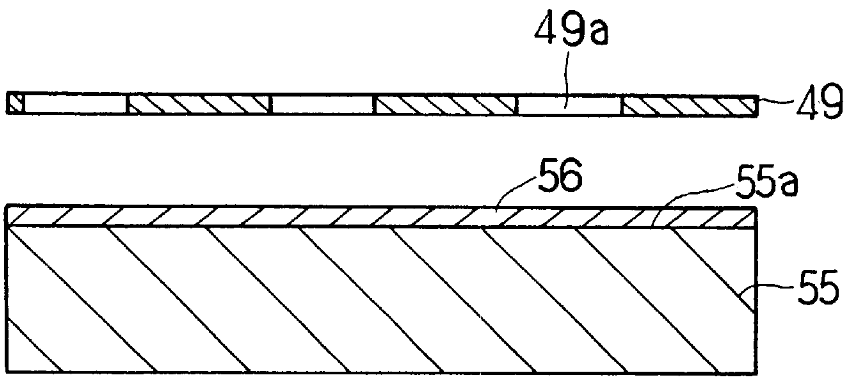


FIG. 22

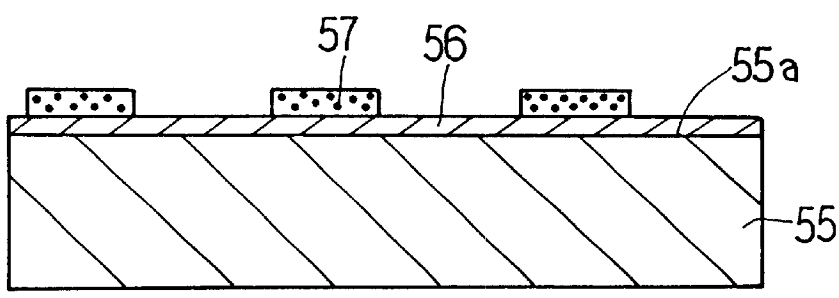


FIG. 23

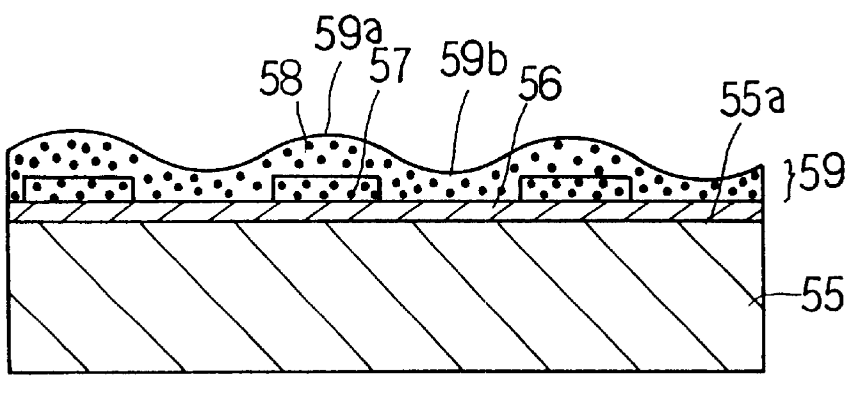


FIG. 24

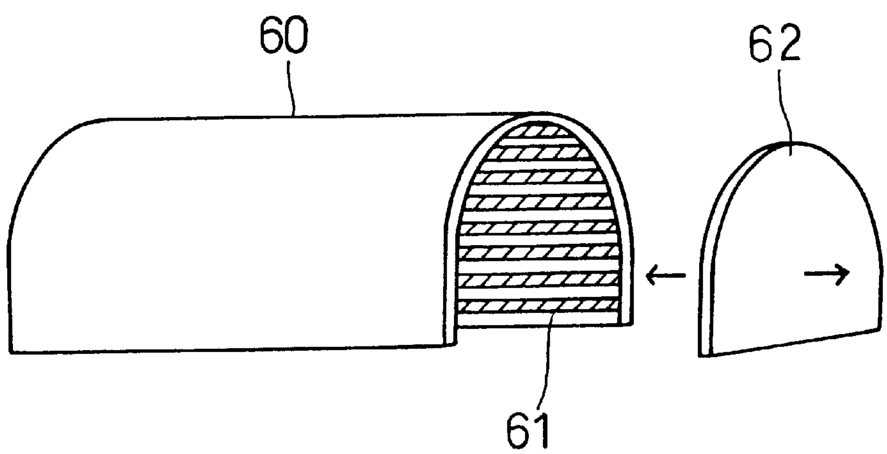


FIG. 25

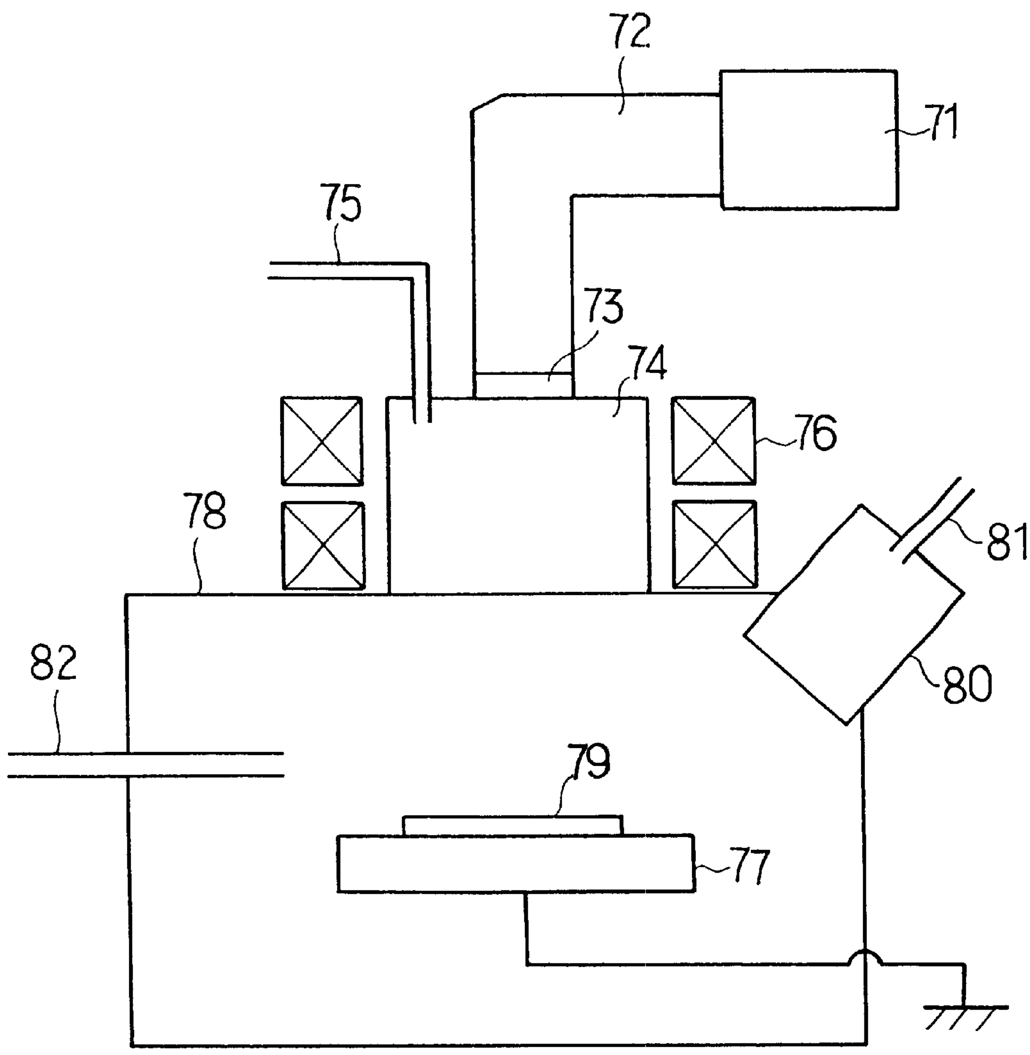


FIG. 26

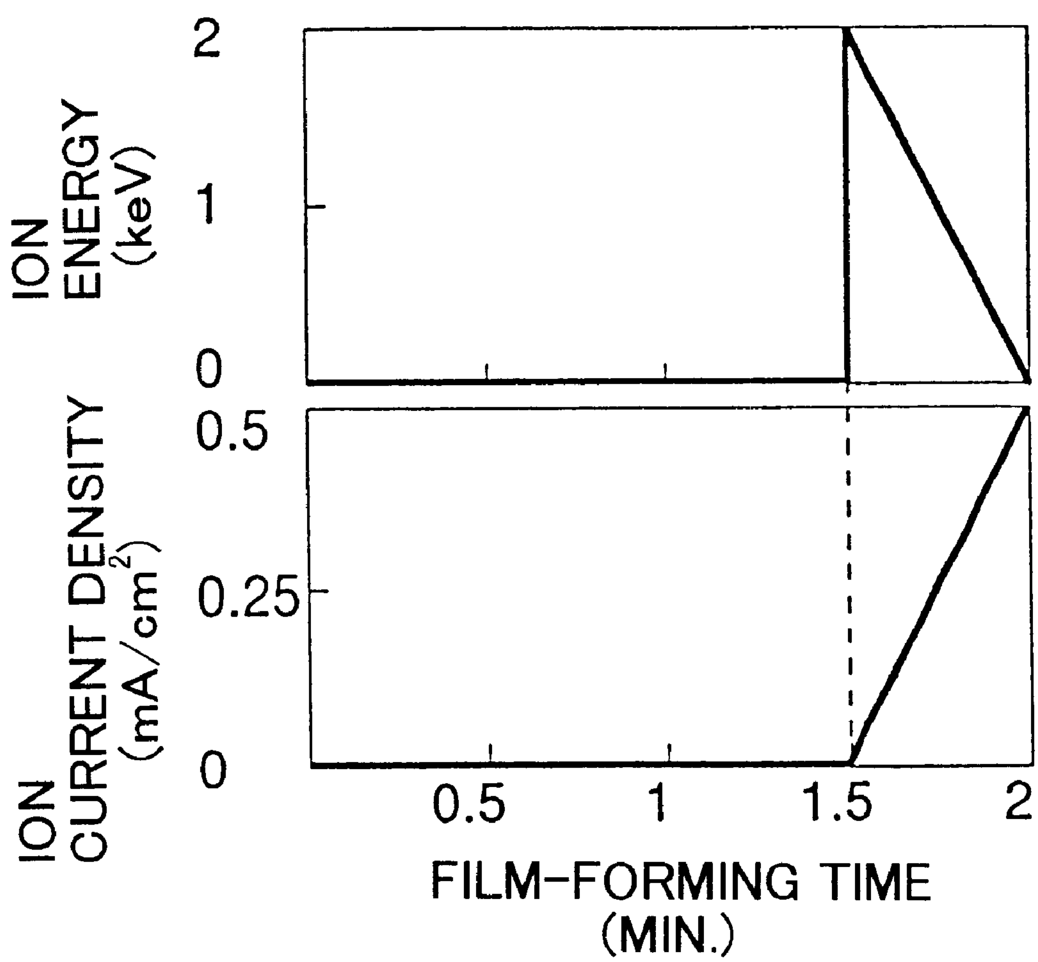

ION ENERGY (keV)
2
1
0
ION CURRENT DENSITY (mA/cm2)
0.5
0.25
0
0.5
1
1.5
2
FILM-FORMING TIME (MIN.)

FIG. 27

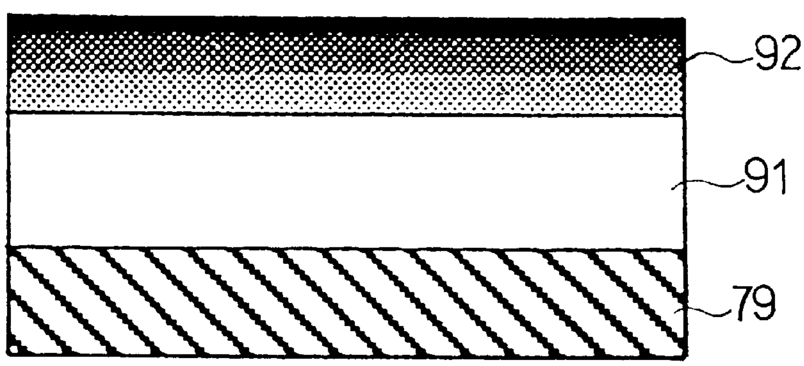


FIG. 28

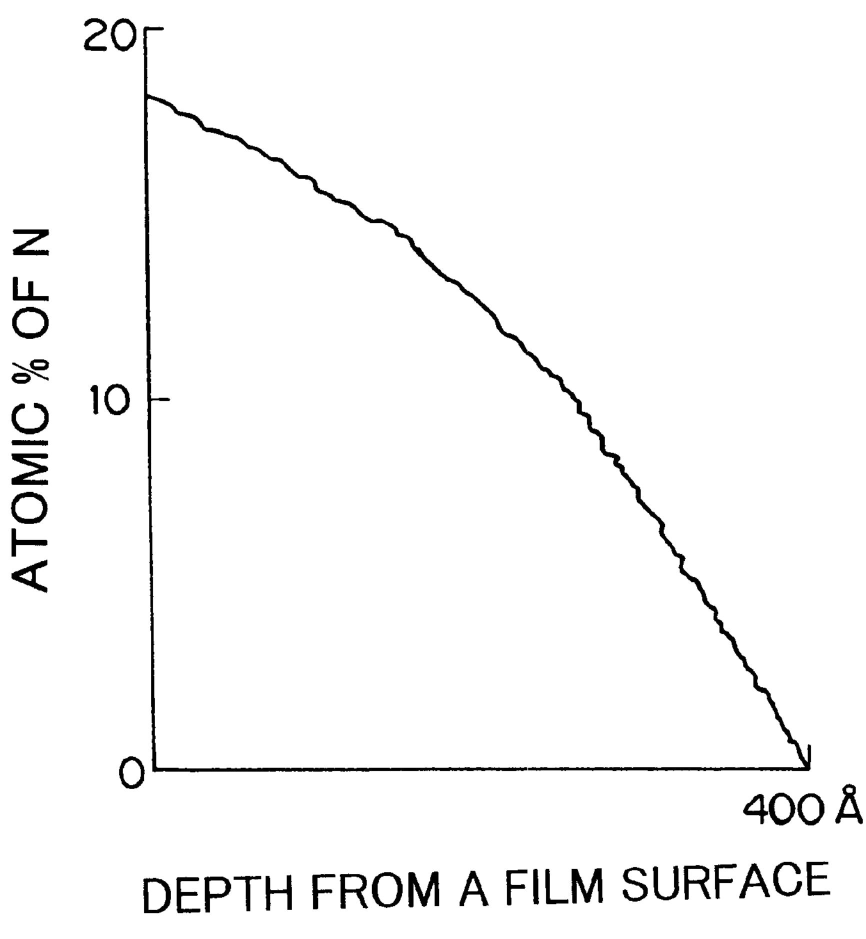


FIG. 29

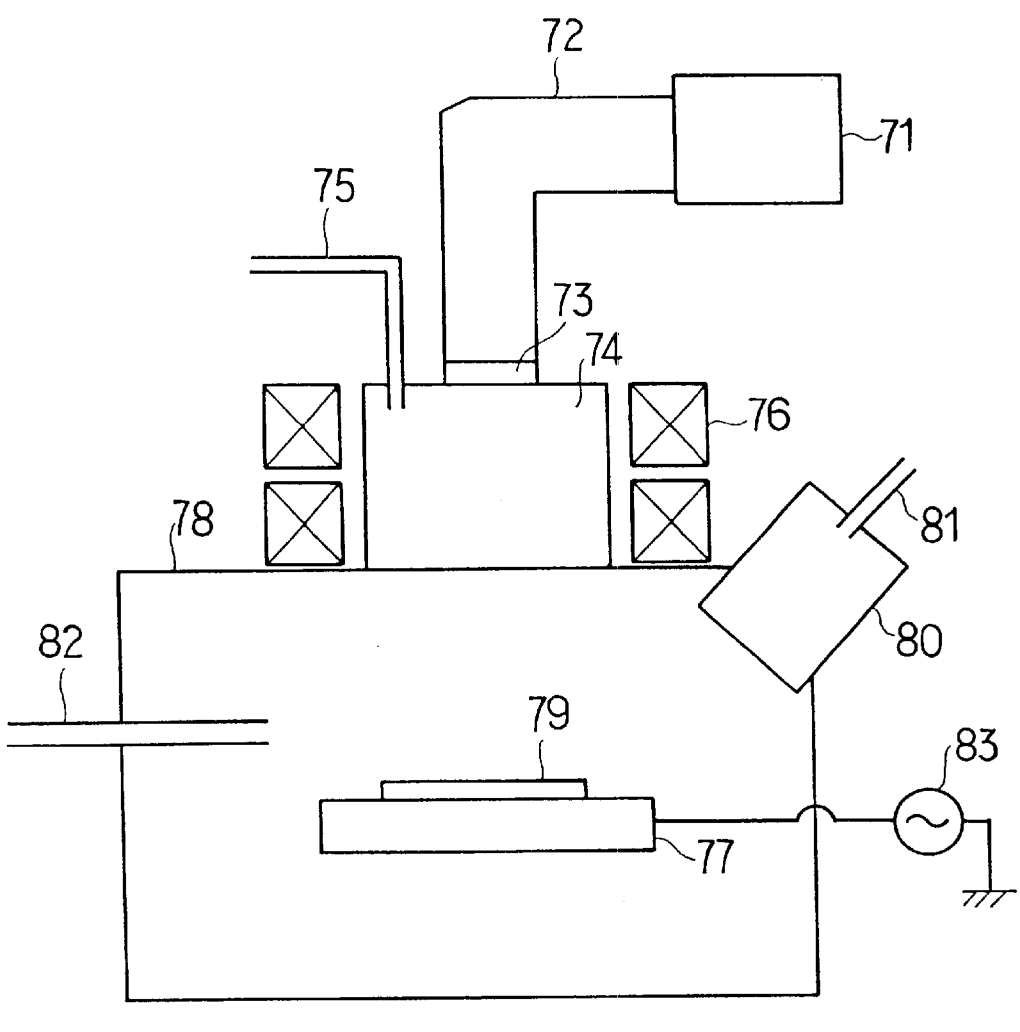
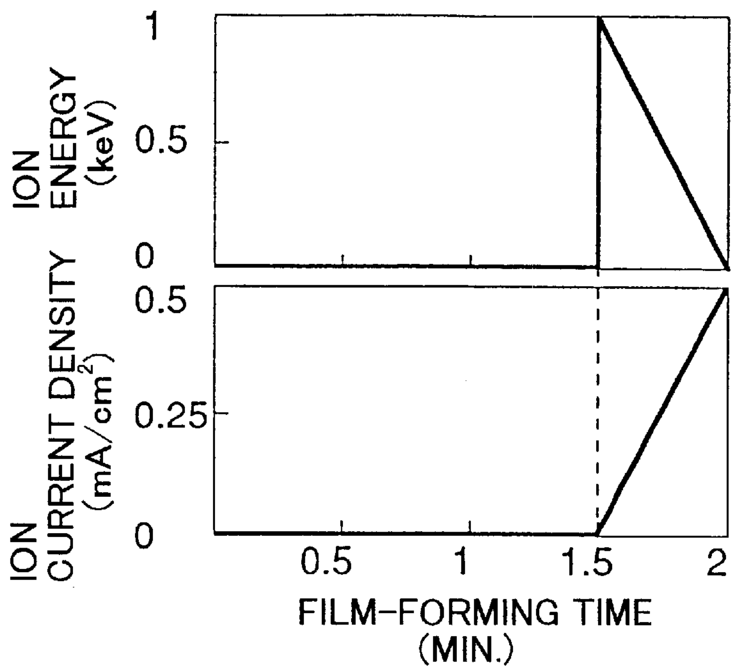
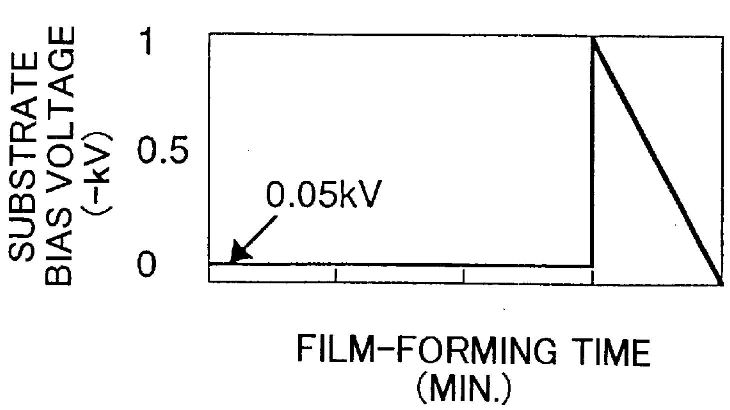


FIG. 30



ION ENERGY (keV)
1
0.5
0
ION CURRENT DENSITY (mA/cm²)
0.5
0.25
0
0.5
1
1.5
2
FILM-FORMING TIME (MIN.)

FIG. 31



SUBSTRATE BIAS VOLTAGE (-kV)
1
0.5
0
0.05kV
FILM-FORMING TIME (MIN.)

FIG. 32

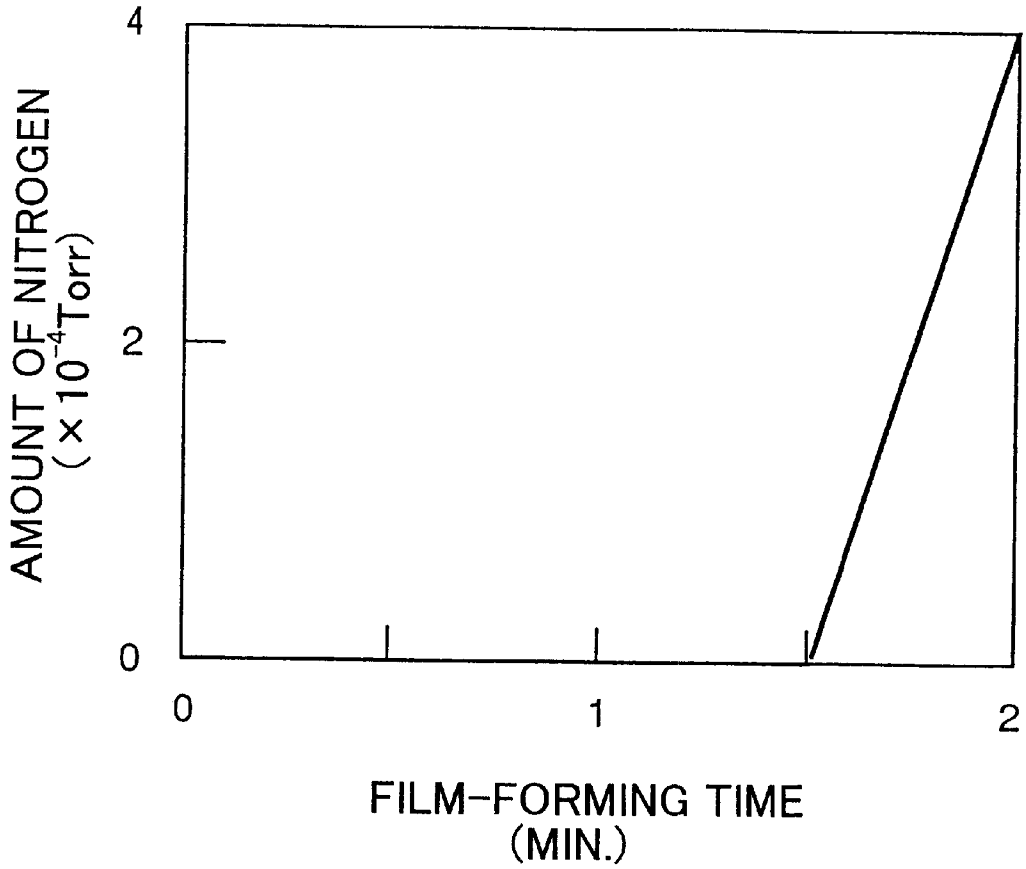


FIG. 33

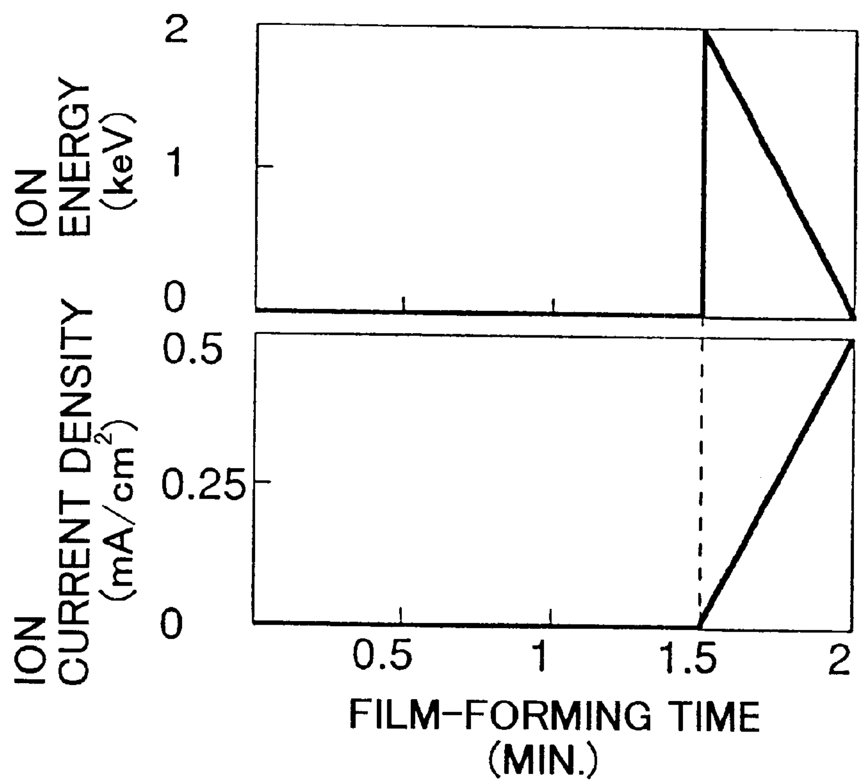
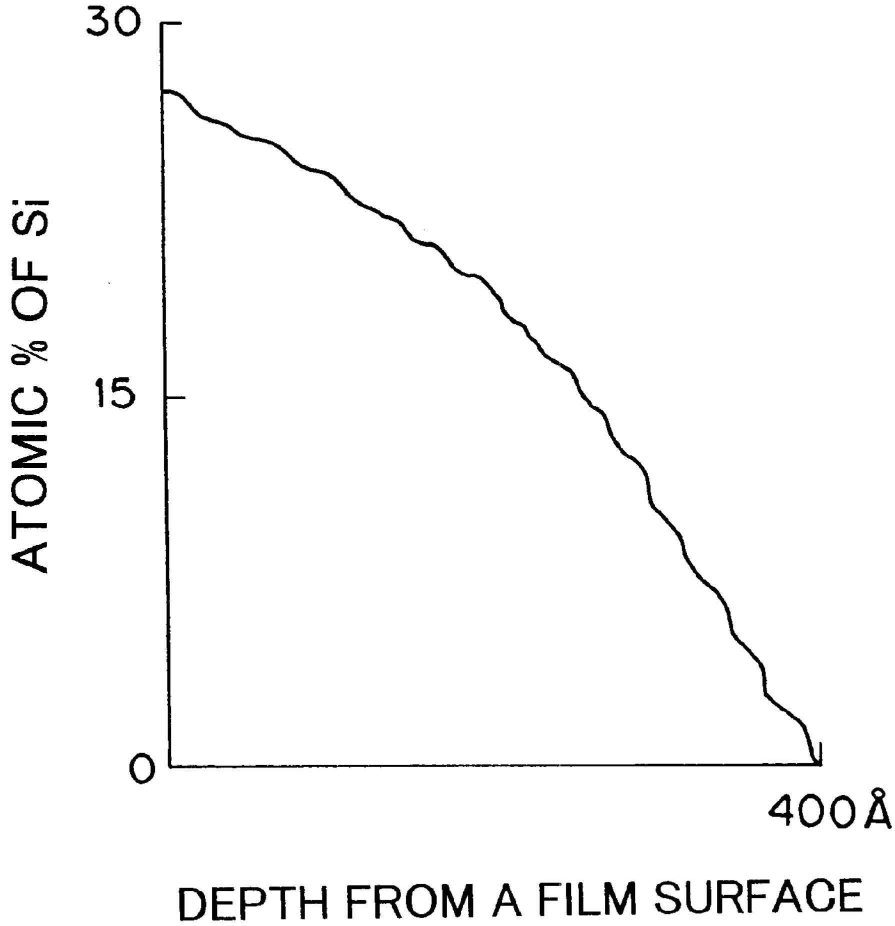

ION ENERGY (keV)
2
1
0
ION CURRENT DENSITY (mA/cm^2)
0.5
0.25
0
0.5
1
1.5
2
FILM-FORMING TIME (MIN.)

FIG. 34



SLIDING MEMBER, INNER AND OUTER BLADES OF AN ELECTRIC SHAVER AND FILM-FORMING METHOD

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to sliding members having a sliding surface for sliding contact with a cooperative member, such as inner and outer blades of an electric shaver, compressor parts, VTR parts and thin film magnetic heads. The present invention further relates to a method of forming a film on a substrate by utilizing a CVD method.

2. Description of Related Art

Investigations have been made as to the formation of a protective film, such as a nitride or diamond-like carbon film, on a skin-contacting, outer surface of an outer blade of an electric shaver, which can impart improved wear-resistance thereto. However, the formation of protective film on an inner surface of the outer blade, which is brought into contact with an inner blade of the electric shaver, has not been put into general practice up to date. Likewise, the formation of protective film on an sliding surface of a distal edge of the inner blade of electric shaver, which is brought into contact with the outer blade, has not been put into general practice up to date.

The inventors of the present application have investigated to what extent wear-resistance can be improved by providing a protective film, such as a diamond-like carbon film, on a sliding surface of an inner or outer blade of an electric shaver, and found that such formation of protective film on the sliding surface results in delamination thereof from the sliding surface or in cutout thereof at the edges of sliding surface, which causes wear of the sliding surface.

Such occurrence of delamination or cutout of the protective film is not limited to the cases where it is applied to the inner or outer blade of an electric shaver, and can also be found in the cases where it is applied onto sliding surfaces, such as of sliding parts of compressor, sliding members of VTR and thin film magnetic heads.

For these sliding members, a protective film is sought which exhibits reduced amount of wear and excellent sliding characteristics.

A plasma CVD method, which deposits a film by decomposing a source gas in a plasma, has been widely used as a measure of forming a film at a relatively low temperature, and is capable of forming films having various compositions by suitably selecting the source gas. Such a CVD method can be utilized to form various films, such as diamond-like carbon films having high degrees of hardness, carbon nitride (CN) and carbon silicide (CSi) films respectively having low levels of friction coefficient.

For example, a diamond-like carbon film, when formed on a silicon substrate, shows a good adhesion to the silicon substrate. However, when attempted to form a carbon nitride or carbon silicide film on the silicon substrate by using conventional film-forming techniques, there arises a problem of poor adhesion therebetween.

SUMMARY OF THE INVENTION

A first object of the present invention is to prevent delamination or cutout of a protective film provided on a sliding surface of a sliding member.

A second object of the present invention is to provide a sliding member carrying on its sliding surface a protective film which exhibits a reduced level of wear and is excellent in sliding characteristics.

A third object of the present invention is to provide a method of forming a film which is as highly functional as a carbon nitride or carbon silicide film and which exhibits good adhesion to a substrate by utilizing a plasma CVD method.

A sliding member in accordance with a first aspect of the present invention is the sliding member having a sliding surface for sliding contact with a cooperative member. A protective film is deposited over the sliding surface and a surface region immediately adjacent the sliding surface in such a characteristic manner that a ratio d**1**/d**2** is controlled to be less than 1, wherein d**1** is a thickness of the protective film overlying the sliding surface and d**2** is a thickness of the protective film overlying the surface region immediately adjacent the sliding surface.

In a first preferred embodiment according to the first aspect of the present invention, the sliding member is an inner blade of an electric shaver. That is, the electric shaver inner blade of this embodiment has at its distal end a sliding surface for sliding contact with an outer blade of the electric shaver. A protective film is deposited not only on the sliding surface but also on side regions of the inner blade immediately adjacent the sliding surface, in such a characteristic manner that a ratio d**1**/d**2** is controlled to be not less than 1, wherein d**1** is a thickness of the protective film overlying the sliding surface and d**2** is a thickness of the protective film overlying the side regions.

In a second preferred embodiment according to the first aspect of the present invention, the sliding member is an outer blade of an electric shaver. That is, the electric shaver outer blade of this embodiment defines a sliding surface, which is brought into sliding contact with an electric shaver inner blade, on its inner surface region around a hole for catching the beard. The outer blade carries the protective film not only on its sliding surface but also on an outer surface region around the hole in such a characteristic manner that a ratio d**1**/d**2** is controlled to be not less than 1, wherein d**1** is a thickness of the protective film overlying the sliding surface and d**2** is a thickness of the protective film overlying the outer surface region.

In the first aspect of the present invention, the region immediately adjacent the sliding surface refers to the region which extends from an edge of the sliding surface at least a distance corresponding in dimension to the thickness of the protective film overlying the sliding surface.

In the first aspect of the present invention, the aforementioned thickness ratio d**1**/d**2** is not less than 1, as specified above, preferably in the range of 1.05~5.0, more preferably in the range of 1.1~3.3.

The deposition of the protective film not only on the sliding surface but also on the region immediately adjacent the sliding surface, in accordance with the first aspect of the present invention, effectively prevents the occurrence of delamination or cutout of the protective film. If the thickness d**2** of protective film, either deposited on the side regions immediately adjacent the sliding surface of the electric shaver inner blade, or deposited on the outer surface region of the electric shaver outer blade around the hole for catching the beard, is controlled to fall within the above-specified range, the delamination or cutout of the protective film on the sliding surface of either member can be prevented, while either member can maintain its function as a sliding member.

In the first aspect of the present invention, the thickness ratio d**1**/d**2** of the protective films is controlled to fall within the range as specified above. The thickness d**1** of protective

film on the sliding surface is suitably selected depending on the particular uses of sliding members, but is generally preferred to fall within the approximate range of 50 Å~10 μm.

In the first aspect of the present invention, the hardness of protective film is preferably not less than 1000 Hv, more preferably not less than 1500 Hv.

A sliding member in accordance with the second aspect of the present invention is the sliding member having a sliding surface for sliding contact with a cooperative member. The sliding member carries a protective film at least on its sliding surface. Characteristically, the protective film is varied in thickness to have projected and depressed portions which together define an irregular surface profile.

In the second aspect of the present invention, the projected and depressed portions of the protective film may be arranged in either regular or irregular pattern. For example, the projected and depressed portions of the protective film may be alternatingly arranged to provide a striped pattern on the surface of the protective film.

In the second aspect of the present invention, the difference in height between the neighboring projected and depressed portions is not particularly specified, but may be in the range of 100~1000 Å. In a particular case where the electric shaver outer blade is selected as the sliding member, a center distance between the neighboring projected and depressed portions of the protective film may be about 1~3 mm, for example.

In the second aspect of the present invention, the different color tones can be imparted to the projected and depressed portions of the protective film by using as the protective film a transparent film which, due to optical interference, assumes different color tones depending on its thickness. The wear of protective film generally progresses at its projected portions brought into direct contact with a cooperative member. As these projected portions wear to get thinner, their color tone is caused to change. Accordingly, the degree of wear of the protective film can be identified by visually observing the change in color tone of such projected portions. This helps us to find the time to replace the sliding member, for example.

The second aspect of the present invention may incorporate the first aspect of the present invention. That is, when the protective film is deposited not only on the sliding surface but also on the region immediately adjacent the sliding surface, the thickness ratio d**1**/d**2** may be controlled to be not less than 1 wherein d**1** is the thickness of the protective film on the sliding surface and d**2** is the thickness of the protective film on the region immediately adjacent the sliding surface. In this instance, the irregular surface profile may be imparted at least to the protective film on the sliding surface.

In the following description, the matters common to the first and second aspects of the present invention may be referred to as those of "the present invention".

Exemplary of the protective film are hard carbon films comprised of diamond and/or amorphous carbon having a diamond structure, and ceramic films.

Specific examples of the hard carbon films include a crystalline diamond film, an amorphous diamond-like carbon film and a diamond-like carbon film partly containing a crystalline structure. The hard carbon film of the present invention may contain the other elements, such as nitrogen and Si, in a mixed fashion.

Examples of the ceramics for use in the protective film of the present invention include oxides, nitrides and carbides of Zr, Ti, Cr, Hf, B, C, Ta, Al and Si.

Other than the aforementioned hard carbon films and ceramic films, metal films such as of Cr and Ni can also be used for the protective film. Such metal films can be formed by plating, for example.

The protective film of the present invention can be formed as by an ECR plasma CVD method and an ion beam deposition method. Other applicable methods include sputtering methods, the other types of PVD and CVD methods, and plating.

The protective film of the present invention may be deposited on an interlayer which has been deposited to cover the sliding surface and the surface region immediately adjacent the sliding surface of the sliding member. The thickness of the interlayer on the sliding surface is preferably made about comparable to that on the surface region immediately adjacent the sliding surface. However, they may be differentiated from each other. The thickness of the interlayer is preferably in the approximate range of 50 Å~8000 Å.

The sliding member of the present invention is illustrated as the electric shaver inner blade in the first embodiment and as the electric shaver outer blade in the second embodiment. However, the sliding member of the present invention can also be applied to the other sliding members, e.g., parts of a compressor such as a rotary compressor. Specifically, the present invention can be applied to rotary compressor parts including a roller, cylinder, vane, and a member having channels for receiving the cylinder. The present invention is also applicable to sliding parts of a VTR, and a thin film magnetic head for use in a hard disk drive (HDD). The present invention is further applicable to a sliding member such as a mask screen which is used to locate a solder at a target position when electronic parts are mounted on a printed circuit board.

The material type of the sliding member in the present invention is not particularly limited, and may be stainless steel, iron-based alloys, cast irons (Mo—Ni—Cr cast iron), steel (high-speed tool steel), aluminum alloys, carbons (aluminum-impregnated carbons), ceramics (oxides, nitrides, or carbides of Ti, Al, Zr, Si, W and Mo), Ni alloys, Ti alloys, or super hard alloys (WC, TiC, or BN), for example.

A method in accordance with a third aspect of the present invention is the method which deposits a film having a thickness varied in a manner to define an irregular surface by using a CVD technique. This method is characterized as comprising the steps of providing a distribution of lines of magnetic force above the substrate, and depositing the film on the substrate so that the film is varied in thickness in a pattern corresponding to the distribution of lines of magnetic force to define said irregular surface.

Although not intended to limit the scope of the present invention, the method in accordance with the third aspect of the present invention may be employed to form the protective film of the sliding member in accordance with the second aspect of the present invention.

In the third aspect of the present invention, the distribution of lines of magnetic force can be produced above the substrate by using various techniques. For example, it can be produced by placing a magnet beneath the substrate. In this instance, the substrate, if magnetic, can be fixed in position by the magnet.

A method in accordance with a fourth aspect of the present invention is also the method which deposits a film having a thickness varied in a manner to define an irregular surface by using a CVD technique. This method is charac-

terized as comprising the steps of depositing a first film on selected regions of a substrate, and depositing a second film over an entire surface of the substrate carrying the first film so that a film comprising the first and second films can be produced which is varied in thickness to have relatively thick portions corresponding in location to said selected regions for defining said irregular surface.

Although not intended to limit the scope of the present invention, the method in accordance with the fourth aspect of the present invention may be employed to form the protective film of the sliding member in accordance with the second aspect of the present invention.

In the fourth aspect of the present invention, the deposition of first film on the selected-regions of the substrate can be accomplished, for example, by using a mask which functions to confine the deposition of first film on the selected regions of the substrate.

Examples of the film deposited in accordance with the third and fourth aspects of the present invention include hard carbon films comprised of diamond and/or amorphous carbon having a diamond structure, and ceramic films.

A method in accordance with a fifth aspect of the present invention is the method which deposit a film on a substrate by a CVD technique utilizing a plasma. The method includes the steps of decomposing a source gas in a plasma to deposit a first film layer on the substrate, and directing ions or radicals onto the substrate, while decomposing the source gas in the plasma, to deposit a second film layer on the first film layer to thereby provide the film on the substrate.

In the fifth aspect of the present invention, the ions or radicals for use in the deposition of the second film layer may generally be of an element different in type from a principal constituent element of the source gas. If contemplated forming the first and second film layers respectively from a carbon film and a carbon nitride or carbon silicide film, for example, a gas comprised principally of carbon, such as a CH_4 gas, may generally be used as the source gas and the ions or radicals of silicon or nitrogen may be directed onto the substrate. However, the ions or radicals for use in the deposition of the second film layer may be of the same element as principally constituting the source gas.

In the fifth aspect of the present invention, the applicable source gases, other than the gas comprised principally of carbon, include the gases which, as a principal component, contains silicon, titanium, zirconium, boron, hafnium, or aluminum. The applicable ions or radicals for use in the deposition of the second film layer, other than the aforementioned ions or radicals of silicon and nitrogen, include those of carbon, oxygen and hydrogen.

In accordance with the fifth aspect of the present invention, the first film layer may be made from a film which is well-adherent to the substrate, and the second film layer may be made from a film, such as a carbon nitride or carbon silicide film, which is poorly-adherent to the substrate but has desired functions. Accordingly, the deposition of such a functional, second film layer on the substrate, through the first film layer, results in the formation of a functional film showing good adhesion to the substrate.

In the film-forming method in accordance with the fifth aspect of the present invention, during the formation of the second film layer, the irradiation energy and dose of ions or radicals may be varied with film-forming time. Such variations in irradiation energy and dose of ions or radicals are effective to cause the distribution of the ion or radical component introduced into the second film layer to be varied in a thickness direction of the second film layer.

By reducing the irradiation energy of ions or radicals with film-forming time and increasing the irradiation dose of ions or radicals with film-forming time, a concentration of the ion or radical component introduced into the second film layer can be increased toward its surface so that a concentration gradient of the component is produced in the thickness direction of the second film layer.

The introduction of such a concentration gradient of the component into the second film layer imparts the improved function to the surface of the second film layer. The second film layer, if made from a carbon nitride or carbon silicide film, exhibits the reduced coefficient of friction toward its surface. The provision of the concentration gradient also results in the formation of a film which exhibits the improved adhesion to a substrate and is imparted thereto the satisfactory functions.

A film-forming method in accordance with a sixth aspect of the present invention is the method of depositing a film on a substrate by a CVD technique utilizing a plasma, and includes the steps of decomposing a source gas in a plasma to thereby deposit a first film layer on a substrate; and applying a radio-frequency power to the substrate for producing a substrate bias voltage (self-bias voltage) and concurrently irradiating the substrate with ions or radicals, while the source gas is decomposed in the plasma, to thereby deposit a second film layer on the first film layer.

In the sixth aspect of the present invention, the ions or radicals for use in the deposition of the second film layer may generally be of an element different in type from a principal constituent element of the source gas. If contemplated forming the first and second film layers respectively from a carbon film and a carbon nitride or carbon silicide film, for example, a gas comprised principally of carbon, such as a CH_4 gas, may generally be used as the source gas and the ions or radicals of silicon or nitrogen may be directed onto the substrate. However, the ions or radicals for use in the deposition of the second film layer may be of the same element as principally constituting the source gas.

In the sixth aspect of the present invention, the applicable source gases, other than the gas comprised principally of carbon, include the gases which contains, as a principal component, silicon, titanium, zirconium, boron, hafnium, or aluminum. The applicable ions or radicals for use in the deposition of the second film layer, other than the aforementioned ions or radicals of silicon and nitrogen, include those of carbon, oxygen and hydrogen.

In accordance with the sixth aspect of the present invention, the first film layer may be made from a film which is well-adherent to the substrate, and the second film may be made from a film, such as a carbon nitride or carbon silicide film, which is poorly-adherent to the substrate but has desired functions. Accordingly, the deposition of such a functional, second film on the substrate, through the first film, results in the formation of a functional film showing good adhesion to the substrate.

Also in the film-forming method in accordance with the sixth aspect of the present invention, during the formation of the second film layer, the irradiation energy and dose of ions or radicals, as well as the substrate bias voltage, may be varied with film-forming time. Such variations in irradiation energy of ions or radicals and the others are effective to cause the distribution of the ion or radical component introduced into the second film layer to be varied in a thickness direction of the second film layer.

By reducing the irradiation energy of ions or radicals and the substrate bias voltage with film-forming time and

increasing the irradiation dose of ions or radicals with film-forming time, a concentration of the ion or radical component introduced into the second film layer can be increased toward its surface so that a concentration gradient of the component is produced in the thickness direction of the second film layer.

The introduction of such a concentration gradient of the component into the second film layer imparts the improved function to the surface of the second film layer. The second film layer, if made from a carbon nitride or carbon silicide film, exhibits the reduced coefficient of friction toward its surface. The provision of the concentration gradient also results in the formation of a film which exhibits the improved adhesion to a substrate and is imparted thereto the satisfactory functions.

In the sixth aspect of the present invention, the application of radio-frequency power to the substrate causes the production of negative bias voltage in the substrate, as stated above. Such a negative bias voltage, if produced, generally acts to attract positive ions to the substrate so that they are preferentially introduced into the second film layer. Accordingly, in the sixth aspect of the present invention, those positive ions, if directed onto the substrate during the deposition of second film layer, are preferentially incorporated into the second film layer.

Also in the sixth aspect of the present invention, the radio-frequency power may be applied to the substrate to produce the substrate bias voltage during the deposition of first film layer on the substrate.

A film-forming method in accordance with a seventh aspect of the present invention is the method of depositing a film on a substrate by a CVD technique utilizing a plasma, and includes the steps of decomposing a source gas in a plasma to thereby deposit a first film layer on a substrate, and decomposing the source gas, as well as a second source gas which contains an element different in type from a principal constituent element of the source gas, in the plasma to thereby deposit a second film layer on the first film layer.

In the seventh aspect of the present invention, the second film layer can be formed which contains the element different in type from the constituent component of the first film layer, by decomposing the source gas and the second source gas in the plasma. It accordingly becomes possible, for example, to form a carbon-based film as the first film layer and subsequently form a film containing an element other than carbon, such as a carbon nitride or carbon silicide film, as the second film layer. In this exemplary case, the second source gas contains nitrogen or silicon.

In the seventh aspect of the present invention, the source gas may be varied in amount with film-forming time. Such a variation in amount of the second source gas with film-forming time leads to the varied distribution in concentration of the element contained in the second source gas in a thickness direction of the second film layer. For example, the increase in amount of the second source gas results in the formation of the second film layer which has an increased concentration of the element contained in the second source gas toward its surface so that a concentration gradient thereof is produced in the thickness direction of the second film layer.

The films of the present invention can be formed by using the film-forming methods in accordance with the aforementioned fifth, sixth and seventh aspects of the present invention. That is, the film of the present invention includes the first film layer comprised of a hard carbon film, and the second film layer deposited on the first film layer and containing nitrogen or silicon as well as the constituent component of the first film layer.

In the aforementioned fifth, sixth and seventh aspects of the present invention, the film of the present invention can be obtained by forming a hard carbon film as the first film layer and subsequently forming a carbon film containing nitrogen or silicon as the second film layer.

In forming the film of the present invention, a carbon-containing gas, such as a methane gas, may be used. In the fifth and sixth aspects of the present invention, ions or radicals of nitrogen or silicon may be directed onto the substrate. In the seventh aspect of the present invention, a gas containing nitrogen or silicon may be used as the second source gas.

In the present invention, the hard carbon film for constituting the first film layer may be a crystalline diamond film, an amorphous diamond-like carbon film, or a diamond-like carbon film partly having a crystalline structure.

In the film of the present invention, the thicknesses of the first and second film layers are not particularly specified. Although not limiting, the thickness of the first film layer is generally in the range of 20 Å~3000 Å, and the thickness of the second film layer is generally in the range of 30 Å~4 μm (40,000 Å).

The nitrogen or silicon content of the second film layer is preferably in the approximate range of 5~40 atomic %.

The concentration of nitrogen or silicon in the second film layer may be graded in a thickness direction thereof. In the preferred embodiment, the second film layer has such a concentration gradient in its thickness direction that the concentration of nitrogen or silicon is increased toward a surface of the second film layer.

The films formed by using the film-forming methods in accordance with the fifth through seventh aspects of the present invention, as well as the films in accordance with the present invention, may further have an interlayer interposed between the first film layer and the substrate. Such an interlayer may be formed of Si, Ti, Zr, W, Mo, Ru or Ge, or an oxide, nitride or carbide of any of thereof, for example. The interlayer can be formed by using generally-employed film-forming techniques. A magnetron RF sputtering technique, for example, can be utilized to form the interlayer. Such a sputtering technique generally uses the aforementioned metal element as a target which is sputtered by ions in argon plasmas to deposit a film. The sputtering, if accompanied by the introduction of an oxygen or nitrogen gas into a chamber, can deposit an oxide or nitride of the metal element as the interlayer. The sputtering, if accompanied by the introduction of a carbon-containing gas, such as a CH_4 gas, into the chamber, can deposit a carbide of the metal element as the interlayer.

The thickness of the interlayer may be in the approximate range of 20 Å~3000 Å, for example.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a sectional view of one embodiment of an electric shaver outer blade in accordance with the first aspect of the present invention;

FIG. **2** is a sectional view of one embodiment of an electric shaver inner blade in accordance with the first aspect of the present invention;

FIG. **3** is a sectional view showing a set of the electric shaver outer blade shown in FIG. **1** and the electric shaver inner blade shown in FIG. **2**.

FIG. **4** is a plan view showing the shape of a hole provided in the electric shaver outer blade shown in FIG. **1**;

FIG. **5** is a side view showing the side of the electric shaver inner blade;

FIG. **6** is a sectional view of another embodiment of an electric shaver outer blade in accordance with the first aspect of the present invention;

FIG. **7** is a sectional view of another embodiment of an electric shaver inner blade in accordance with the present invention;

FIG. **8** is a side view showing a number of outer blades placed in position for film deposition on their respective sliding surfaces;

FIG. **9** is a side view showing a number of inner blades placed in position for film deposition on their respective sides;

FIG. **10** is a schematic block diagram showing one example of an ECR plasma CVD apparatus;

FIG. **11** is a schematic block diagram showing an apparatus for vacuum evaporation and ion implantation, for use in the formation of a ZrN film;

FIG. **12** is a graph showing the level of occurrence of delamination or cutout of a protective film and the level of cutting quality in relation to d**1**/d**2** as varied in one embodiment in accordance with the first aspect of the present invention;

FIG. **13** is a graph showing the level of occurrence of delamination or cutout of a protective film and the level of cutting quality in relation to d**1**/d**2** as varied in another embodiment in accordance with the first aspect of the present invention;

FIG. **14** is a graph showing the level of occurrence of delamination or cutout of a protective film and the level of cutting quality in relation to d**1**/d**2** as varied in a still another embodiment in accordance with the first aspect of the present invention;

FIG. **15** is a plan view showing one embodiment of a protective film deposited on a sliding member in accordance with a second aspect of the present invention;

FIG. **16** is a sectional view showing the protective film of FIG. **15**;

FIG. **17** is a plan view showing one example of magnet for use in a third aspect of the present invention;

FIG. **18** is a sectional view showing the magnet of FIG. **17**;

FIG. **19** is a plan view showing another example of magnet for use in the third aspect of the present invention;

FIG. **20** is a sectional view showing one embodiment for practicing a film-forming method in accordance with the third aspect of the present invention;

FIGS. **21** through **23** are sectional views showing one embodiment for practicing a film-forming method in accordance with a fourth aspect of the present invention;

FIG. **24** is a perspective view showing inner and outer blades of an electric shaver for use in one embodiment in accordance with the second aspect of the present invention;

FIG. **25** is a schematic sectional view showing an exemplary ECR plasma CVD apparatus for use in an embodiment for practicing the method in accordance with a fifth aspect of the present invention;

FIG. **26** is a graph showing the variations of ion energy and ion current density with film-forming time, during the deposition of a second film layer, in an embodiment for practicing the method in accordance with the fifth aspect of the present invention;

FIG. **27** is a sectional view showing a film embodiment in accordance with the present invention;

FIG. **28** is a graph showing a distribution of nitrogen concentration in a thickness direction of a second film layer incorporated in the film embodiment in accordance with the present invention;

FIG. **29** is a schematic sectional view showing an exemplary ECR plasma CVD apparatus for use in an embodiment for practicing the method in accordance with a sixth aspect of the present invention;

FIG. **30** is a graph showing the variations of ion energy and ion current density with film-forming time, during the deposition of the second film layer, in the embodiment for practicing the method in accordance with the sixth aspect of the present invention;

FIG. **31** is a graph showing the variation of substrate bias voltage with film-forming time, during the deposition of the second film layer, in the embodiment for practicing the method in accordance with the sixth aspect of the present invention;

FIG. **32** is a graph showing the variation of nitrogen amount with film-forming time, during the deposition of a second film layer, in an embodiment for practicing the method in accordance with a seventh aspect of the present invention;

FIG. **33** is a graph showing the variations of ion energy and ion current density with film-forming time, during the deposition of the second film layer, in another embodiment for practicing the method in accordance with the fifth aspect of the present invention; and

FIG. **34** is a graph showing a distribution of Si concentration in a thickness direction of a second film layer incorporated in another film embodiment in accordance with the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIGS. **1** through **3** are sectional views showing inner and outer blades of an electric shaver, each as a sliding member in accordance with the first aspect of the present invention. FIG. **1** shows the electric shaver outer blade and FIG. **2** shows the electric shaver inner blade. FIG. **3** is a sectional view showing the positional arrangement of the electric shaver outer blade relative to the electric shaver inner blade. As shown in FIG. **3**, the electric shaver inner blade **11** is disposed inwardly of the electric shaver outer blade **1**. The electric shaver inner blade **11**, when operated to move to and fro in the direction indicated by the arrows in FIG. **3**, cuts off the beard caught in a hole **6** of the electric shaver outer blade **1**. As also shown in FIG. **3**, an inner surface portion of the outer blade **1** that extends to surround the hole **6** defines a sliding surface **2** for sliding contact with the electric shaver inner blade **11**. A distal end of the electric shaver inner blade **11** also defines a sliding surface **12**. The beard caught in the hole **6** of the electric shaver outer blade **1** is cut off by a shear force produced between an edge of the sliding surface **2** of the electric shaver outer blade **1** and an edge of the sliding surface **12** of the electric shaver inner blade **11**.

FIG. **4** is a plan view showing the shape of the holes **6** provided in the electric shaver outer blade **1**. FIG. **5** is a side view showing the shape of one side of the electric shaver inner blade **11**. As shown in FIG. **4**, a number of holes **6** is provided in the electric shaver outer blade **1** for catching the beard. Also, the electric shaver outer blade **1** is formed from a soft material so that it can slidably receive the distal end, i.e., the sliding surface **12** of the electric shaver inner blade **11** shown in FIG. **5**.

FIG. **1** is an enlarged sectional view of the electric shaver outer blade **1**. As shown in FIG. **1**, a protective film **5***b* is

provided on an outer surface **3** of the electric shaver outer blade **1**. Another protective film **5***a* is provided on an inner surface **4**, including the sliding surface **2**, of the electric shaver outer blade **1**. As can be seen from FIG. **1**, a thickness of the protective film **5***b* provided on the outer surface **3** is denoted by d**2**. A thickness of the protective film **5***a* provided on the inner surface **4** is denoted by d**1**. In the first aspect of the present invention, the protective films **5***a* and **5***b* are respectively provided such that the ratio d**1**/d**2** is not less than 1, preferably in the range of 1.05~5.0, more preferably in the range of 1.1~3.3.

FIG. **2** is an enlarged sectional view of the electric shaver inner blade. As shown in FIG. **2**, a protective film **15***a* is provided on a distal end, i.e., a sliding surface **12** of the electric shaver inner blade **11**. The electric shaver inner blade **11** further carries protective films **15***b* on its sides **13** and **14**. In this particular embodiment, the protective film **15***b* is deposited on opposing parallel sides **13** and **14** of the inner blade, which respectively cross a sliding direction thereof. As can be seen from FIG. **2**, a thickness of the protective film **15***a* provided on the sliding surface **12** is denoted by d**1**, and a thickness of the protective film **15***b* provided on each of the sides **13** and **14** is denoted by d**2**. In the first aspect of the present invention, the protective films **15***a* and **15***b* are respectively provided such that the ratio d**1**/d**2** is not less than 1, preferably in the range of 1.05~5.0, more preferably in the range of 1.1~3.3.

In the first aspect of the present invention, the protective film **5***b* may be provided to overly at least a limited region of the outer surface immediately adjacent or neighboring the sliding surface **2**, although shown in FIG. **1** as being provided over an entire region of the outer surface **3**. Accordingly, it should be understood that the protective film **5***b* may be provided only on the limited region of the outer surface **3** immediately adjacent the hole **6** shown in FIG. **3**, for the electric shaver outer blade shown in FIG. **1**.

Also in the first aspect of the present invention, its is necessary that the protective film **5***a* be provided to cover at least the sliding surface **2**, although shown to cover an entire region of the inner surface **4** of the electric shaver outer blade **1** in the embodiment shown in FIGS. **1** and **3**.

Further in the first aspect of the present invention, it is necessary that the protective film **15***b* be provided on the electric shaver inner blade **1** to cover at least a limited region of each side **13**, **14** thereof that immediately neighbors the sliding surface **12**, although shown to cover an entire region of each side **13**, **14** in the embodiment shown in FIGS. **2** and **3**. Accordingly, the protective film **15***b* may be provided to cover each side region that extends inwardly from the edge **15***a* a distance not smaller in dimension than the thickness d**1** of the protective film **15***a*.

FIGS. **6** and **7** are sectional views respectively showing further embodiments of outer and inner blades of an electric shaver in accordance with the first aspect of the present invention. FIG. **6** shows the electric shaver outer blade and FIG. **7** shows the electric shaver inner blade. In this particular embodiment, the electric shaver outer blade **1** carries thereon an interlayer **6** on which protective films **5***a* and **5***b* are formed, as shown in FIG. **6**. Even in the case where the interlayer **6** is such provided, the thickness d**1** of the protective film **5***a* provided on the sliding surface **2**, as well as the thickness d**2** of the protective film **5***b* provided on the region of outer surface **3** immediately adjacent the sliding surface **2**, are adjusted to fall within the ranges specified in the first aspect of the present invention.

Likewise, the electric shaver inner blade **11** carries thereon an interlayer **16** on which protective films **15***a* and **15***b*, are provided, as shown in FIG. **7**. Again, for this electric shaver inner blade, the thickness d**1** of the protective film **15***a* provided on the sliding surface **12**, as well as the thickness d**2** of the protective film **15***b* provided on the region of each side **13** and **14** immediately neighboring the sliding surface **12**, are adjusted to fall within the ranges specified in the first aspect of the present invention.

FIGS. **15** and **16** are views showing a protective film provided on a sliding surface of a sliding member in accordance with the second aspect of the present invention. FIGS. **15** and **16** are a plan view and a sectional view, respectively. As shown in FIG. **16**, a protective film **52** is deposited on a sliding surface **51***a* of a sliding member **51**. The protective film **52** includes relatively thick, projected portions **52***a* and relatively thin, depressed portions **52***b*, arranged in alternating and continuous fashions. As shown in FIG. **15**, the projected portions **52***a* (indicated by crosshatching) and depressed portions **52***b* are such arranged to define a striped pattern.

The projected portions **52***a* of the protective film **52** shown in FIG. **16** are those portions that will be brought into sliding contact with a cooperative member. Such construction serves to reduce a contact area of the protective film with the cooperative member and is thus effective in reducing a frictional resistance and accordingly improving its wear resistance. Also, the progress of wear can be detected from change in color tone of the protective film **52**, if it is formed from a transparent film which, due to optical interference, assumes different color tones depending on its thickness. That is, a degree of wear of the protective film **52** can be identified by visually observing the change of color tone at the projected portions **52***a* which, when contacted with a cooperative member, wears and reduces its thickness. For example, if the projected portions **52***a* present a color tone different from that of the depressed portions **52***b*, a striped pattern shown in FIG. **15** appears. As the wear progresses at the projected portions **52***a* to such an extent that they approximate in thickness to the depressed regions **52***b*, their respective color tones come closer to each other so that the striped pattern comes to disappear. Thus, the wear degree of the protective film **52** can be identified by visually observing such disappearance of the striped pattern. This suggests a timing for replacement of a sliding member, for example. Exemplary of the transparent film which, due to optical interference, assumes different color tones depending on its thickness is a diamond-like carbon film. As the diamond-like carbon film is gradually reduced in thickness, its color tone changes periodically in the sequence of "yellow", "red", "violet", "blue", "blue-green", "green" and "yellow".

The second aspect of the present invention may incorporate the aforementioned, first aspect of the present invention. In determining the thickness d**1** of protective film on the sliding surface and of the thickness d**2** of protective film on the region neighboring the sliding surface, the irregularities of the protective film are then averaged to obtain an average film thickness.

The protective film shown in FIGS. **15** and **16** as having a varying thickness can be formed, for example, by using the film-forming methods in accordance with the third and fourth aspects of the present invention.

FIGS. **17** and **18** are views showing one example of a magnet which is employed in the film-forming method according to the third aspect of the present invention for providing a distribution of lines of magnetic force above a substrate. FIGS. **17** and **18** are a plan view and a sectional

view, respectively. As shown in FIG. **18**, a magnet **53** is magnetized to produce discrete regions wherein N- and S-poles of the discrete region are reversed in position in the neighboring discrete region. Accordingly, a set of the N-pole **53***a* and S-pole **53***b* is arranged in a repeated fashion on either side of the magnet to define a striped pattern, as shown in FIG. **17**. The use of such a magnet **53** results in the formation of the protective film which includes relatively thick portions corresponding in location to the N-poles or S-poles and relatively thin portions corresponding in location to boundaries of the neighboring N- and S- poles. A plastic magnet may be employed as the aforementioned magnet **53**, for example. Alternatively, a plurality of magnets or electromagnets may suitably be arranged to constitute the magnet **53**.

FIG. **19** is a plan view showing another example of the magnet. In this magnet **54**, N-poles **54***a* (or S-poles) are dispersed like islands within an S-pole **54***b* (or N-pole). The use of such a magnet enables formation of the protective film in which either the relative thick, projected portions or relatively thin, depressed portions are dispersed like islands.

The suitable positional arrangement of the N- and S-poles, in the manner as stated above, to make a desired design, pattern or character results in formation of the protective film having projected or depressed portions arranged in accordance with the desired design or the other.

FIG. **20** is a sectional view showing one embodiment for practicing a film-forming method in accordance with the third aspect of the present invention. As shown in FIG. **20**, the magnet **51** is placed beneath a substrate, i.e., beneath the sliding member **51** to provide a desired distribution of lines of magnetic force above the substrate **51**. When the protective film **52** is subsequently deposited on the substrate **51**, irregularities are given thereto in a pattern corresponding to the distribution of lines of magnetic force. The protective film **52** can be formed which includes projected portions **52***a* and depressed portions **52***b* arranged in a striped pattern as shown in FIGS. **15** and **16**, by utilizing the magnet having a surface on which N-poles and S-poles are distributed in a striped pattern, as shown in FIGS. **17** and **18**. Specifically, the projected portions **52***a* can be formed corresponding in location to the N-poles or S-poles, while the depressed portions **52***b* can be formed corresponding in location to boundaries of the neighboring N- and S-poles.

FIGS. **21** through **23** are sectional views showing one embodiment for practicing the film-forming method in accordance with the fourth aspect of the present invention.

Referring to FIG. **21**, an interlayer **56** is deposited on a sliding surface **55***a* of a sliding member or substrate **55**. Such an interlayer **56** can be formed of at least one type of material selected from Si, Zr, Ti, Ru, Ge and oxides, carbides and nitrides thereof. The interlayer can be interposed between the protective film and the sliding surface of sliding member, in the first and second aspects of the present invention. Also in the aforementioned third aspect of the present invention, the interlayer can be deposited on the substrate for subsequent provision of the protective film on the interlayer. The provision of the interlayer serves to improve adherence of the protective film to the sliding surface.

FIG. **21** shows a mask **49** disposed above the interlayer **56**. The mask **49** has openings **49***a* provided at predetermined locations. A first protective film is to be deposited on the interlayer **56** through the mask **49**.

FIG. **22** shows the first protective film **57** such deposited on the interlayer **56** through the mask **49**.

A second protective film **58** is then deposited over an entire upper surface of the substrate **55**. The first protective film **57** and the second protective film **58**, formed in the manner as described above, together constitute a protective film **59**. The protective film **59** has relatively thick, projected portions **59***a* at locations where the first protective films **57** reside, and relatively thin, depressed portions **59***b* at locations where the first protective films **57** are devoid. Accordingly, a protective film can be formed which has projected and depressed portions arranged in a striped pattern, analogous to the protective film **52** shown in FIGS. **15** and **16**, for example, by providing a striped pattern of the first protective film **57**. Also, a desired design, pattern or character can be given on the protective film, by providing the first protective film **57** at locations where relatively thick, projected portions are desired to be formed. Furthermore, such a design or the other can be given by different color tones, by using as the protective film a particular film which, due to optical interference, presents different color tones depending on its thickness.

A specific example of depositing a protective film on a sliding member in accordance with the first aspect of the present invention is described below.

Example of Depositing a Hard Carbon Film on an Electric Shaver Inner Blade

First, an Si interlayer was deposited on an electric shaver inner blade made of a stainless steel (SUS) by using a CVD method. In depositing a film on the sliding surface **12** of the electric shaver inner blade **11**, the following procedure was followed. As shown in FIG. **8**, plural electric shaver inner blades **11**, arranged side by side on a holder **20**, were flanked by a pair of jigs **21** and **22**. Then, a film was deposited to cover all of the respective sliding surfaces **12** of the electric shaver inner blades.

In depositing a film on a side of the electric shaver inner blade **11**, the following procedure was followed. The plural electric shaver inner blades **11** were arranged end to end on a holder **23** so as for one side **13** of each electric shaver inner blade **11** to face upward. Then, a film was deposited to cover all of the respective sides **13** of the electric shaver inner blades **11**.

The Si interlayer was deposited on each of the sliding surface **12** and sides **13**, **14** to a thickness of 500 Å.

Thereafter, a diamond-like carbon film was deposited on the interlayer of the electric shaver inner blade. The diamond-like carbon film was deposited, through the interlayer, not only on the sliding surface in the manner as shown in FIG. **8**, but also on each side in the manner as shown in FIG. **9**.

FIG. **10** is a schematic sectional view showing an exemplary ECR plasma CVD apparatus for use in the formation of a diamond-like carbon film. Referring to FIG. **10**, a vacuum chamber **38** has a plasma generation chamber **34** to which one end of a waveguide **32** is connected. Another end of the waveguide **32** is mounted to a microwave supplying means **31**. A microwave generated in the microwave supplying means **31** passes through the waveguide **12** and a microwave inlet window **33** to be guide into the plasma generation chamber **34**. The plasma generation chamber **34** is provided with a gas inlet line **35** for introducing a discharge gas such as an argon (Ar) gas thereinto. Also, a number of plasma magnetic field generators **36** is mounted around the plasma generation chamber **34**. A high-density ECR plasma can be generated within the plasma generation chamber **34** through the interaction of a radio-frequency

magnetic field produced by the microwave and a magnetic field produced by the plasma magnetic field generators **36**.

The vacuum chamber **38** houses a holder **37** on which a sample piece **30** is placed for coverage with a diamond-like carbon film. The holder **37** is electrically connected to a radio-frequency power source **40**. The application of an RF power from the radio-frequency power source **40** to the holder **37** causes the sample piece to generate a self-bias voltage. The vacuum chamber **38** is also provided with a source gas inlet line **39** for introducing thereinto a source gas, such as methane (CH_4) or hydrogen (H_2). The source gas, when introduced from the source gas inlet line **39**, is decomposed by the action of a plasma from the plasma generation chamber **34**, resulting in the deposition of a diamond-like carbon film on the sample piece **30**.

The following film-forming conditions were employed: Ar gas partial pressure of 5.7×10^{-4} Torr., CH4 gas partial pressure of 1.3×10^{-3} Torr., microwave frequency of 2.45 GHz, and microwave power of 100 W. A 13.56 MHZ RF power from the radio-frequency power source **40** was applied to the holder in a controlled fashion so that a self-bias voltage of −50 V was generated at the sample piece **30**.

First, a sample of electric shaver inner blade was fabricated which had a 2000 Å thick, diamond-like carbon film solely on its sliding surface **12**. The sample inner blade of electric shaver was combined with an electric shaver outer blade, made of SUS, to set an electric shaver which was continuously operated for two weeks. Thereafter, the electric shaver inner blade was observed for a degree of wear. As a result, delamination or partial cutout of the diamond-like carbon film, as a protective film, was noticed at the edges **12***a* (see FIGS. **2** and **7**) of the electric shaver inner blade **12** where its sliding surface **12** met respective sides **13** and **14**.

Next, a protective film, i.e., a diamond-like film was deposited on each of a sliding surface and both sides of an electric shaver inner blade. In depositing the diamond-like carbon film on each side, its thickness was altered at 1000 Å, 2000 Å, and 3000 Å. As a result, three types of sample inner blades were fabricated. In the same manner as described above, each sample inner blade thus obtained was combined with an electric shaver outer blade, made of SUS, to set an electric shaver which was continuously operated for two weeks. Thereafter, the electric shaver inner blade was observed for a degree of wear. For those inner blades having different thicknesses, neither delamination of the diamond-like carbon film nor partial cutout thereof at the edges **12***a* was noticed. The delamination of the protective film or partial cutout thereof at the edges can be prevented by depositing the protective film not only on the sliding surface but also on the region(s) immediately adjacent the sliding surface.

Then, these shavers were used to cut acrylic, artificial hairs. The cut surfaces of hairs were observed to count the proportion thereof that exhibited good cut surfaces. The electric shaver inner blades respectively carrying 1000 Å, 2000 Å and 3000 Å thick, protective films on their sides gave the results of 95%, 80% and 65%, respectively.

It has been found from these results that the cutting quality of electric shaver is reduced as the thickness (3000 Å) of protective film on each side exceeds the thickness (2000 Å) on the sliding surface, i.e., as the ratio d**1**/d**2** falls below 1. This reduced cutting quality of electric shaver is believed likely due to the increased thickness of protective film on the sides relative to the protective film on the sliding surface, which reduces the sharpness of the inner blade edges.

In the same manner as described above, the sample inner blades of electric shaver were fabricated. A diamond-like carbon film was deposited on a sliding surface of each sample inner blade to a thickness of 2000 Å. Also, a diamond-like carbon film was deposited on respective sides of the sample inner blades to the following different thicknesses; 200 Å (d**1**/d**2**=10.0), 400 Å (d**1**/d**2**=5.0), 600 Å (d**1**/d**2**=3.3), 1000 Å (d**1**/d**2**=2.0), 1800 Å (d**1**/d**2**=1.1), 1900 Å (d**1**/d**2**=1.05), 2000 Å (d**1**/d**2**=1.0) and 3000 Å (d**1**/d**2**=0.7). These sample inner blades were observed for occurrence of delamination of protective film or partial cutout thereof at the edges of sliding surface, and were also evaluated for cutting qualities thereof in the same manner as described above. The results are given in FIG. **12**. In FIG. **12**, ○ indicates the degree of occurrence of delamination or partial cutout of the protective film. Fifty samples were prepared for each sample inner blade, and evaluation was made by counting the number of samples, out of fifty samples, that exhibited neither delamination of the protective film nor partial cutout thereof at the edges of sliding surface and determining the rate. Accordingly, 100% indicates that neither delamination of the protective film nor partial cutout thereof at the edges of sliding surface was noticed.

Also, ▲ indicates the level of cutting quality. In the same manner as above, fifty samples were prepared for each sample inner blade. After cutting of acrylic, artificial hairs by using those samples, evaluation was made by counting the number of samples, out of fifty samples, that imparted good cut surfaces to the respective hairs and determining the rate.

As can be appreciated from FIG. **12**, the electric shaver inner blade, if its d**1**/d**2** falls within the range of 1.05~5.0, more preferably within the range of 1.1~3.3, exhibits reduced occurrence of delamination or partial cutout of the protective film, as well as an increased level of cutting quality.

Example of Depositing a Hard Carbon Film on an Electric Shaver Outer Blade

Next, a diamond-like carbon film, as a protective film, was formed on an electric shaver outer blade made of Ni. In the same manner as in the above Example, an Si interlayer was formed on each of outer and inner surfaces of the electric shaver outer blade to a thickness of 500 Å. Also in the same manner as described above, the ECR plasma CVD apparatus was employed to form the diamond-like carbon film, through the interlayer, exclusively on the inner surface (including the sliding surface **2**) shown in FIG. **6** to a thickness of 2000 Å.

This sample outer blade having the outer surface left uncovered by a diamond-like carbon film was combined with an electric shaver inner blade, made of SUS, to set an electric shaver which was then operated continuously for two weeks. The inner surface of outer blade was subsequently observed for degree of wear. The partial cutouts of the diamond-like carbon film, as the protective film, were noticed at the edges of the sliding surface.

Sample outer blades were then fabricated carrying a diamond-like carbon film not only on the inner surface but also on the outer surface **3** shown in FIG. **6**. However, those sample outer blades had 1000 Å, 2000 Å and 3000 Å thick, diamond-like carbon films on their respective outer surfaces.

Each of the sample outer blades thus obtained was combined with an inner blade made of SUS to set an electric shaver for continuous operation, in the same manner as

described above. The sample outer blades were observed for degree of wear. None of those sample outer blades showed cutout of protective film at the edges of sliding surface. This demonstrates that the deposition of protective film not only on the sliding surface but also on its adjacent surface regions of the electric shaver outer blade effectively prevents delamination of the protective film, as well as cutout of the protective film at the edges of sliding surface.

The sample outer blades were then subjected to the aforementioned cutting test using artificial hairs. The sample outer blades respectively carrying 1000 Å, 2000 Å and 3000 Å thick protective films on their respective outer surfaces gave the results of 95%, 80% and 65%, respectively. It has been found from these results that as the thickness **d2** of protective film on the outer surface exceeds the thickness **d1** on the sliding surface within the inner surface, i.e., as the ratio **d1**/**d2** falls below 1, the sharpness of the outer blade is reduced at its edges, resulting in reduced cutting quality of the electric shaver incorporating such an outer blade.

Pursuant to the aforementioned procedures, the outer blade of electric shaver was fabricated. A diamond-like carbon film was deposited on an inner surface of the outer blade to a thickness of 2000 Å. Also, a diamond-like carbon film was deposited on an outer surface of the outer blade to the following different thicknesses; 200 Å (**d1**/**d2**=10.0), 400 Å (**d1**/**d2**=5.0), 600 Å (**d1**/**d2**=3.3), 1000 Å (**d1**/**d2**=2.0), 1800 Å (**d1**/**d2**=1.1), 1900 Å (**d1**/**d2**=1.05), 2000 Å (**d1**/**d2**=1.0) and 3000 Å (**d1**/**d2**=0.7). The sample outer blades thus obtained were observed for occurrence of delamination of the protective film or partial cutout at the edges of sliding surface, and were also evaluated for a level of cutting quality in the same manner as described above. The results are given in FIG. **13**. In FIG. **13**, ○ indicates the degree of occurrence of delamination or partial cutout of the protective film. Fifty samples were prepared for each sample outer blade, and evaluation was made by counting the number of samples, out of fifty samples, that exhibited neither delamination of protective film nor partial cutout thereof at the edges of sliding surface and determining the rate. Accordingly, 100% indicates that neither delamination of the protective film nor partial cutout thereof at the edges of sliding surface film was noticed.

Also, ▲ indicates the level of cutting quality. In the same manner as above, fifty samples were prepared for each sample outer blade. After cutting of acrylic, artificial hairs by using the samples, evaluation was made by counting the number of samples, out of fifty samples, that imparted good cut surfaces to the respective hairs and determining the rate.

As can be appreciated from FIG. **13**, the electric shaver outer blade, if its **d1**/**d2** falls within the range of 1.05~5.0, more preferably within the range of 1.1~3.3, exhibits reduced occurrence of delamination or partial cutout of its protective film, as well as increased level of cutting quality.

Example of Depositing a Zirconium Nitride (ZrN) Film on an Electric Shaver Outer Blade

A ZrN film, as a protective film, was deposited on an electric shaver outer blade made of Ni. In this Example, the ZrN film was deposited directly on the electric shaver outer blade.

FIG. **11** shows an apparatus for vacuum deposition and ion implantation, for use in the formation of the ZrN film. A vacuum chamber **41** houses a holder **42** which is rotatable in the direction of the shown arrow at a rate of 10~20 rpm. The holder **42** mounts a sample piece **30** thereon. The vacuum chamber **41** is provided with an evaporation source **43** which evaporates zirconium (Zr) atoms for direction onto the sample piece **30**. The vacuum chamber is further provided with an assist ion gun **44** which is operable to either emit nitrogen ions (N^+) or supply a nitrogen gas (N_2) toward the sample piece **30**. This ion gun **44**, while emitting N^+ ions, may also emit nitrogen atoms (N), although slight in amount, which have failed to become ions.

The interior of vacuum chamber **41** is evacuated to a pressure of 10^{-5}~10^{-7} Torr., followed by supply of an N_2 gas into the assist ion gun **44** which emits N^+ ions toward a surface of the sample piece **30**. The acceleration voltage and ion current density of N^+ ions are set at 700 eV and 0.38 mA/cm^2, respectively.

Concurrently with the emission of N^+ ions by the assist ion gun, the evaporation source **43** is driven to evaporate Zr atoms for direction onto the surface of sample piece **30**. The evaporation rate of Zr is controlled to measure 650 Å/min when converted to a film-forming rate on the sample piece **30**.

In the procedure as stated above, a ZrN film was first formed solely on an inner surface of an electric shaver outer blade to a thickness of 2000 Å. The sample outer blade thus obtained was combined with an inner blade made of SUS to set an electric shaver for continuous operation, in the same manner as described above. The sample outer blade was observed for degree of wear of protective film provided on a sliding surface within its inner surface. The partial cutout of the protective film were noticed at the edges of sliding surface of the sample outer blade.

Next, a protective film, i.e., a ZrN film was deposited not only on the inner surface but also on an outer surface of the electric shaver outer blade. However, the ZrN film was deposited on the outer surface to different thicknesses; 1000 Å, 2000 Å and 3000 Å.

In the same manner as described above, each sample outer blade thus obtained was combined with an electric shaver inner blade to set an electric shaver for continuous operation. Thereafter, the sample outer blades were observed for degrees of wear at their respective sliding surfaces. None of them showed cutout of protective film at the edges of sliding surface. This demonstrates that the delamination of the protective film or partial cutout of the protective film at the edges of sliding surface can be prevented by depositing a protective film not only on the sliding surface but also on its adjacent, outer surface region around the opening.

Next, the shavers incorporating these sample outer blades were subjected to the cutting test using artificial hairs. The cutting qualities thereof were observed by counting the proportion of hairs which exhibited good cut surfaces. The electric shaver outer blades respectively carrying 1000 Å, 2000 Å and 3000 Å thick, protective films gave the results of 95%, 80% and 65%, respectively.

It has been found from these results that as the thickness **d2** of protective film on the outer surface region adjacent the sliding surface is controlled to exceed the thickness **d1** thereof on the sliding surface, i.e., as the ratio **d1**/**d2** is controlled to fall below 1, the sharpness of outer blade is reduced at the edges of its sliding surface to result in the reduced cutting quality thereof.

In the same manner as described above, a ZrN film was deposited on an inner surface of an electric shaver outer blade to a thickness of 2000 Å. Another ZrN film was formed on an outer surface of the outer blade to the following different thicknesses: 200 Å (**d1**/**d2**=10.0), 400 Å (**d1**/**d2**=5.0), 600 Å (**d1**/**d2**=3.3), 1000 Å (**d1**/**d2**=2.0), 1800 Å (**d1**/**d2**=1.1), 1900 Å (**d1**/**d2**=1.05), 2000 Å (**d1**/**d2**=1.0)

and 3000 Å (d1/d2=0.7). In the same manner as described above, the sample outer blades obtained were observed for occurrence of delamination of protective film or partial cutout thereof at the edges of sliding surface, and were also evaluated for cutting quality. The results are given in FIG. **14**. In FIG. **14**, ○ indicates the degree of occurrence of delamination of protective film or partial cutout thereof at the edges of sliding surface. Fifty samples were prepared for each sample outer blade, and evaluation was made by counting the number of samples, out of fifty samples, which exhibited neither delamination of protective film nor partial cutout thereof at the edges of sliding surface and determining the rate. Accordingly, 100% indicates that neither delamination of protective film nor partial cutout thereof at the edges of sliding surface was noticed.

Also, ▲ indicates the level of cutting quality. In the same manner as described above, fifty samples were prepared for each sample outer blade. After cutting of acrylic, artificial hairs by using the samples, evaluation was made by counting the number of samples, out of fifty samples, which imparted good cut surfaces to the respective hairs and determining the rate.

As can be appreciated from FIG. **14**, the electric shaver outer blade, if its d1/d2 falls within the range of 1.05~5.0, more preferably within the range of 1.1~3.3, exhibits the reduced occurrence of delamination or partial cutout of its protective film, as well as increased cutting quality.

The specific examples will be below described which deposit a protective film on an electric shaver outer blade in accordance with the second through fourth aspects of the present invention.

EXAMPLE 1

In this Example, a diamond-like carbon film **61**, as a protective film, was deposited on an inner surface of an electric shaver outer blade **60** made of Ni, as shown in FIG. **24**. The openings provided in the electric shaver outer blade **60** for catching the beard was not shown in FIG. **24**. The electric shaver outer blade **60** shown in FIG. **24** assumes the configuration after subjected to bending processing. The protective film was deposited on the inner surface of the electric shaver outer blade **60** while in a plate form. First, a CVD method was employed, analogously to the above Examples, to deposit an Si interlayer on the inner surface of the plate-form, electric shaver outer blade to a thickness of 500 Å.

The plate-form, electric shaver outer blade carrying the interlayer thereon was then placed on a magnet, as shown in FIGS. **17** and **18**, which produced a distribution of lines of magnetic force above a surface on which a film is to be deposited. While they were maintained under such a condition, a diamond-like carbon film was deposited on the interlayer by employing the ECR plasma CVD apparatus. The positional arrangement of the electric shaver outer blade was adjusted so that a striped pattern consisting of projected and depressed portions of the deposited protective film **61** extends in the sliding direction of an electric shaver inner blade **62**, as shown in FIG. **24**. The projected portions of the protective film **61** are indicated by crosshatching in FIG. **24**. Since the electric shaver outer blade is formed from a magnetic material, it can be fixed on the magnet **53** by the action of magnetic force.

The protective film provided in the manner as stated above measured an average thickness of 2000 Å. The thinnest depressed portion measured a thickness of 1750 Å. The thickest projected portion measured a thickness of 2250 Å. Accordingly, the difference in height between such projected and depressed portions was 500 Å. A center distance between the depressed and projected portions was about 2 mm.

EXAMPLE 2

In the same manner as in Example, an Si interlayer was formed on an inner surface of the plate-form outer blade of electric shaver to a thickness of 500 Å. A diamond-like carbon film, as a protective film, was further deposited on the interlayer by using the method shown in FIGS. **21** through **23**. A 500 Å thick, diamond-like carbon film was deposited to provide a first protective film **57** shown in FIG. **22**. A center distance between the neighboring first protective films **57** was controlled at about 4 mm. Another diamond-like carbon film was deposited to provide a second protective film **58** shown in FIG. **23** having a thickness of about 1750 Å. Accordingly, the thickest projected portion **59***a* of the protective film **59** shown in FIG. **23** measured a thickness of about 2250 Å, while the thinnest depressed portion **59***b* thereof measured a thickness of 1750 Å. A center distance between the neighboring projected and depressed portions was about 2 mm.

Comparative Example 1

In the same manner as in Example 1, an Si interlayer was formed on an inner surface of the plate-form outer blade of electric shaver to a thickness of 500 Å. Thereafter, the ECR plasma CVD apparatus was employed to deposit a 2000 Å thick, diamond-like carbon film on the interlayer. This diamond-like carbon film was a film substantially uniform in thickness.

The electric shaver outer blades obtained from Examples 1 and 2 and Comparative Example 1 were then subjected to bending processing to impart the shape shown in FIG. **24** thereto. Each electric shaver outer blade was arranged to receive an electric shaver inner blade **62** inside thereof for evaluation of wearability. For comparative purposes, an electric shaver outer blade, carrying neither interlayer nor protective film on its inner surface, was also subjected to the evaluation of wearability (Comparative Example 2).

A load current of a motor when driving the electric shaver inner blade was measured. The evaluation in wearability of the outer blades was given by using relative values when the load current measured in Comparative Example 2 was taken as 1. Also, after the electric shaver inner blade was driven for 50 hours, the respective electric shaver outer blade was removed to visually observe any presence of scratches thereon for evaluation of scratch resistance.

The rating ○ indicates that no scratch was noticed, or scratches were noticed in a limited surface region of the outer blade. The rating Δ indicates that scratches were noticed over an entire surface of the outer blade. The rating × indicates that the outer blade was ultimately fractured.

The evaluation results are given in Table 1.

TABLE 1

	EXAMPLE 1	EXAMPLE 2	COMPARATIVE EXAMPLE 1	COMPARATIVE EXAMPLE 2
LOAD CURRENT (RELATIVE VALUE)	0.7	0.7	0.8	1.0
SCRATCH RESISTANCE	○	○	Δ	x

As can be appreciated from the results given in Table 1, the use of electric shaver outer blades of Examples 1 and 2, respectively irregularly-surfaced according to the second aspect of the present invention, results in the reduced load current to the motor, reduced frictional resistance and improved wear resistance. It can also be appreciated that the

respective inner surfaces of the electric shaver outer blades of Examples 1 and 2 were imparted thereto excellent scratch resistances.

Initially, the respective inner surfaces of the electric shaver outer blades of Examples 1 and 2 were visually observed as defining a striped pattern reflecting the varied film thickness. However, as the sliding movement of the inner blade continued for a prolonged period, the progressive wear of the protective film on the inner surface was observed which caused the striped pattern to gradually disappear. Accordingly, the observation of such a striped pattern can be helpful in finding the time to replace the outer blade of electric shaver.

Although the above Examples, according to the second aspect of the present invention, describe the deposition of irregularly-surfaced protective film on the inner surface of the electric shaver outer blade, such an irregularly-surfaced protective film may be deposited on an outer surface of the electric shaver outer blade. In this instance, the outer surface is a sliding surface for contact with a human skin.

In the above Examples according to the first and second aspects of the present invention, the present invention is illustrated as being applied to the inner and outer blades of electric shaver. However, the present invention is not limited to such applications, and can also be applied to sliding parts of a compressor such as a rotary compressor, sliding parts of VTR, thin-film magnetic heads, mask screens and the others.

ECR Plasma CVD Apparatus in Accordance with the Fifth Aspect of the Present Invention

FIG. **25** is a schematic sectional view showing an ECR plasma CVD apparatus in accordance with the fifth aspect of the present invention. Referring to FIG. **25**, a vacuum chamber **78** is provided with a plasma generation chamber **74** to which one end of a waveguide **72** is connected. Another end of the waveguide **72** is mounted to a microwave supplying means **71**. A microwave generated in the microwave supplying means **71** passes through the waveguide **72** and a microwave inlet window **73** to be guide into the plasma generation chamber **74**. The plasma generation chamber **74** is provided with a gas inlet line **75** for introducing a discharge gas such as an argon (Ar) gas into the plasma generation chamber **74**. The vacuum chamber **78** is further provided with a gas inlet line **82** for introducing a source gas, such as methane (CH_4), thereinto. A high density ECR plasma can be produced within the plasma generation chamber **74** through the interaction of a radio-frequency magnetic field produced by the microwave and a magnetic field produced by plasma magnetic field generators **76**. The vacuum chamber **78** encloses a substrate holder **77** on which a substrate is placed. An ion gun **80** is disposed in a suitable position for emission of an ion beam toward the substrate **79**. Connected to this ion gun **80** is a gas inlet line **81** for introducing thereinto a source gas which is to be converted to ions.

EXAMPLE 3

In this Example, the apparatus shown in FIG. **25** is employed to form a diamond-like carbon film, as a first protective film, on which a carbon nitride film is subsequently deposited as a second protective film, in accordance with the fifth aspect of the present invention.

A diamond-like carbon film was first deposited on a substrate by using the ECR plasma CVD method. While the interior of vacuum chamber **78** was evacuated to a pressure of 10^{-5}~10^{-7} Torr., an Ar gas was introduced into the plasma generation chamber **74** at a pressure of 2.5×10^{-4} Torr. for conversion to an Ar plasma within the plasma generation chamber **74**. A source gas, i.e., a CH_4 gas at a pressure of 3.0×10^{-4} Torr. was supplied to the vacuum chamber **78** in which the CH_4 gas was decomposed by the Ar plasma to result in the formation of the diamond-like carbon film on the substrate **79**. An Si substrate was employed for the substrate **79**. The film-forming rate and film thickness were 800 Å/min and 1200 Å, respectively.

Next, a nitrogen gas at a pressure of 2×10^{-4} Torr. from the gas inlet line **81** was delivered to the ion gun **80** which subsequently emitted nitrogen ions onto the substrate **79**, concurrently with the above-described formation of diamond-like carbon film by means of the ECR plasma CVD method. During the emission of nitrogen ions, the ion energy and ion current density were both varied with film-forming time, as shown in FIG. **26**. Specifically, the ion energy was decreasingly varied from 2 keV to 0 keV with film-forming time of the second film layer, and the ion current density was increasingly varied from 0 to 0.5 mA/cm^2 with film-forming time of the second film layer. In this manner, the formation of second film layer was continued for 0.5 minutes to provide the second film layer having a thickness of 400 Å. As a result, a film was formed including the first and second film layers. The thickness of the film thus totaled 1600 Å.

FIG. **27** is a sectional view showing the film obtained in the manner as described above. As shown in FIG. **27**, the first film layer **91**, consisting of the diamond-like carbon film, is deposited on the substrate **79**, and the second film layer **92**, consisting of the carbon nitride (CN) film, is deposited on the first film layer **91**.

FIG. **28** is a graph showing the analytical results of the second film layer **92** when subjected to the secondary mass ion spectrometry (SIMS). As can be appreciated from FIG. **28**, the second film layer has an increased nitrogen content toward its surface so that a concentration gradient of nitrogen is produced in its thickness direction.

The samples obtained were then evaluated for adherence. In evaluating the adherence, a constant load (2 kg) indentation test was conducted using a Vickers penetrator. Fifty samples were subjected to the test, and the number of samples that showed delamination of the film from the respective substrata was counted as indicating the level of adherence. For comparative purposes, an N_2 gas at 4×10^{-4} Torr., together with a CH_4 gas, were simultaneously introduced from the gas inlet line **82**. The ECR plasma CVD method was exclusively utilized to deposit a carbon nitride film on a substrate to a thickness of 1600 Å (Comparative Example 3-1). The samples obtained in Comparative Example 3-1 were likewise subjected to the indentation test using a Vickers penetrator for evaluation of adherence.

As a result, the number of samples that showed delamination amounted to 0 in Example 3 but to 40 in Comparative Example 3-1. These results demonstrate that the formation of carbon nitride film, i.e. the second film layer, on the diamond-like carbon film, i.e. the first film layer, improves adherence of the resulting film to the substrate.

Next, the films respectively obtained in Example 3 and Comparative Example 3-1 were measured for hardness. For comparative purposes, only the above procedure to form the first film layer was followed to solely form a diamond-like carbon film on a substrate to a thickness of 1600 Å (Comparative Example 3-2). Like the above, the film obtained in Comparative Example 3-2 was measured for hardness.

The hardness of the film obtained in Comparative Example 3-1, i.e., the hardness of the amorphous carbon

nitride film measured about 2500 Hv, while that of the film obtained in Example 3 measured 3400 Hv. The hardness of the film obtained in Comparative Example 3-2 measured 3500 Hv. These measurement results demonstrate that a film, if constructed by depositing the carbon nitride film, as the second film layer, on the diamond-like carbon film, as the first film layer, is capable of exhibiting the level of hardness almost comparable to that of the diamond-like film.

Next, the films respectively obtained in Example 3 and Comparative Example 3-2 were measured for coefficient of friction. The film of Comparative Example 3-2, a surface of which was defined by the diamond-like carbon film, exhibited a frictional coefficient of 0.18, while the film of Example 3 exhibited a noticeably reduced frictional coefficient of 0.13.

ECR Plasma CVD Apparatus in Accordance with the Sixth Aspect of the Present Invention

FIG. **29** is a schematic sectional view showing an ECR plasma CVD apparatus in accordance with the sixth aspect of the present invention. This apparatus is analogous in construction to the apparatus shown in FIG. **25**, with the exception that a radio-frequency power source **83** is electrically connected to the substrate holder **77** for applying a radio-frequency power to the substrate holder **77**. Accordingly, the detailed discussion of the present apparatus is omitted.

EXAMPLE 4

In this Example, the apparatus shown in FIG. **29** is employed to form a diamond-like carbon film, as a first film layer, on which a carbon nitride film is subsequently formed as a second film layer.

First, the interior of vacuum chamber **78** was evacuated to a pressure of 10^{-5}~10^{-7} Torr. Then, an Ar gas at a pressure of 2.5×10^{-4} Torr. was introduced into the plasma generation chamber **74** to produce an Ar plasma within the plasma generation chamber **74**. A source gas, i.e., a CH_4 gas at a pressure of 3.0×10^{-4} Torr. was supplied to the vacuum chamber **78** in which the CH_4 gas was subsequently decomposed by the Ar plasma to result in the formation of the diamond-like carbon film on the substrate **79**. While the formation of first film layer was continued for 1.5 minutes, a 13.56 MHZ radio-frequency power from the radio-frequency power source **83** was applied to the substrate holder so that a substrate was maintained at a bias voltage of −50 V. The film-forming rate was 800 Å/min and the thickness of first film layer was 1200 Å.

Next, a nitrogen gas at a pressure of 2.5×10^{-4} Torr. from the gas inlet line **81** was delivered to the ion gun **80** which emitted nitrogen ions onto the substrate **79**, concurrently with the above-described formation of diamond-like carbon film. The formation of second film layer was continued for 0.5 minutes to provide the second film layer, i.e., the carbon nitride film having a thickness of 400 Å. As a result, a film was formed including the first and second film layers. The thickness of the film thus totaled 1600 Å. During the formation of second film layer, the ion energy was decreasingly varied from 1 keV to 0 keV while the ion current density was increasingly varied from 0 to 0.5 mA/cm^2, as shown in FIG. **30**. Concurrently, a substrate bias voltage was varied from −1 kV to 0 kV, as shown in FIG. **31**. This resulted in the formation of second film layer which, analogous to the second film layer formed in Example 3, had an increased nitrogen content toward its surface so that a concentration gradient of nitrogen was produced in its thickness direction.

The samples obtained were then evaluated for adherence. In evaluating the adherence, a constant load (2 kg) indentation test was conducted using a Vickers penetrator. Fifty samples were subjected to the test and the number of samples that showed delamination of the film from the respective substrata was counted as indicating the level of adherence. For comparative purposes, an N_2 gas at 4×10^{-4} Torr., as well as a CH_4 gas, were simultaneously introduced from the gas inlet line **82**. The ECR plasma CVD method was exclusively utilized to form a carbon nitride film on a substrate to a thickness of 1600 Å (Comparative Example 4-1). The samples obtained in Comparative Example 4-1 were likewise subjected to the indentation test using a Vickers penetrator for evaluation of adherence.

As a result, the number of samples that showed delamination amounted to 0 in Example 4 but to 40 in Comparative Example 4-1. These results demonstrate that the deposition of carbon nitride film, as the second film layer, on the diamond-like carbon film, as the first film layer, improves the adherence of the resulting film to the substrate.

Next, the films respectively obtained in Example 4 and Comparative Example 4-1 were measured for hardness. For comparative purposes, only the aforementioned procedure to form the first film layer was followed to solely form a diamond-like carbon film on a substrate to a thickness of 1600 Å (Comparative Example 4-2). The film obtained in Comparative Example 4-2 was likewise measured for hardness.

The hardness of the film obtained in Comparative Example 4-1, i.e., the hardness of the amorphous carbon nitride film measured about 2500 Hv, while that of the film obtained in Example 4 measured 3400 Hv. The hardness of the film obtained in Comparative Example 4-2 measured 3500 Hv. These measurement results demonstrate that a film, if constructed by depositing the carbon nitride film, as the second film layer, on the diamond-like carbon film, as the first film layer, is capable of exhibiting the level of hardness almost comparable to that of the diamond-like film.

Next, the films respectively obtained in Example 4 and Comparative Example 4-2 were measured for coefficient of friction. The film of Comparative Example 4-2, a surface of which was defined by the diamond-like carbon film, exhibited a frictional coefficient of 0.18, while the film of Example 4 exhibited a noticeably reduced frictional coefficient of 0.13.

EXAMPLE 5

The apparatus shown in FIG. **29** is employed to form a diamond-like carbon film, as a first film layer, on which a carbon nitride film is subsequently formed as a second film layer, in accordance with the seventh aspect of the present invention. In the present Example, the ion gun **80** in the apparatus shown in FIG. **29** is unemployed.

First, the interior of vacuum chamber **78** was evacuated to a pressure of 10^{-5}~10^{-7} Torr. Then, an Ar gas at a pressure of 2.5×10^{-4} Torr. was introduced into the plasma generation chamber **74** to produce an Ar plasma within the plasma generation chamber **74**. A source gas, i.e., a CH_4 gas at 3.0×10^{-4} Torr. was supplied to the vacuum chamber **78** within which the CH_4 gas was decomposed by the Ar plasma to result in the formation of the diamond-like carbon film on the substrate **79**. While the formation of first film layer was continued for 1.5 minutes, a radio-frequency power from the radio-frequency power source **83** was applied to the substrate holder **77** so that a substrate was maintained at a bias voltage of −50 V. In the manner as described above, the first

film layer was formed at a film-forming rate of 800 Å/min to a thickness of 1200 Å.

A nitrogen gas as a second source gas, together with a CH_4 gas, were delivered to the vacuum chamber from the gas inlet line **82**. A second film layer, i.e., a carbon nitride film was deposited on the above-formed first film layer by the ECR plasma CVD technique using the mixed gas composed of CH_4 and nitrogen gases. The formation of second film layer was continued for 0.5 minutes to provide the carbon nitride film having a thickness of 400 Å. As a result, a film was formed including the first and second film layers. The thickness of the film thus totaled 1600 Å. During the formation of second film layer, the supply pressure of nitrogen gas, as the second source gas, was controlled to gradually increase from 0 to 4×10^{-4} Torr., as shown in FIG. **32**.

This resulted in the formation of second film layer which, analogous to the second film layers respectively formed in Examples 3 and 4, exhibited an increased nitrogen content toward its surface so that a concentration gradient of nitrogen was produced in its thickness direction.

The samples obtained were then evaluated for adherence. In evaluating the adherence, a constant load (2 kg) indentation test was conducted using a Vickers penetrator. Fifty samples were subjected to the test and the number of samples that showed delamination of the film from the substrata was counted as indicating the level of adherence. For comparative purposes, an N_2 gas at 4×10^{-4} Torr., together with a CH_4 gas, were simultaneously introduced from the gas inlet line **82**. The ECR plasma CVD method was exclusively utilized to deposit a carbon nitride film on a substrate to a thickness of 1600 Å (Comparative Example 5-1). The samples obtained in Comparative Example 5-1 were likewise subjected to the indentation test using a Vickers penetrator for evaluation of adherence.

As a result, the number of samples that showed delamination amounted to 0 in Example 5 but to 40 in Comparative Example 5-1. These results demonstrate that the deposition of carbon nitride film, as the second film layer, on the diamond-like carbon film, as the first film layer, improves the adherence of the resulting film to the substrate.

Next, the films respectively obtained in Example 5 and Comparative Example 5-1 were measured for hardness. For comparative purposes, only the aforementioned procedure to form the first film layer was followed to solely form a diamond-like carbon film on a substrate to a thickness of 1600 Å (Comparative Example 5-2). The film obtained in Comparative Example 5-2 was likewise measured for hardness.

The hardness of the film obtained in Comparative Example 5-1, i.e., the hardness of the amorphous carbon nitride film measured about 2000 Hv, while that of the film obtained in Example 5 measured 3200 Hv. The hardness of the film obtained in Comparative Example 5-2 measured 3500 Hv. These measurement results demonstrate that a film, if constructed according to the present invention, i.e., by depositing the carbon nitride film, as the second film layer, on the diamond-like carbon film, as the first film layer, is capable of exhibiting the level of hardness almost comparable to that of the diamond-like film.

Next, the films respectively obtained in Example 5 and Comparative Example 5-2 were measured for coefficient of friction. The film of Comparative Example 5-2, a surface of which was defined by the diamond-like carbon film, exhibited a frictional coefficient of 0.18, while the film of Example 5 exhibited a noticeably reduced frictional coefficient of 0.14.

EXAMPLE 6

In this Example, the apparatus shown in FIG. **25** is employed to form a diamond-like carbon film, as a first protective film, on which a carbon nitride film is subsequently deposited as a second protective film, in accordance with the fifth aspect of the present invention.

In the same manner as in Example 3, a first film layer, i.e., a diamond-like carbon film was first formed to a thickness of 1200 Å.

Next, a silane gas at a pressure of 2×10^{-4} Torr. from the gas inlet line **81** was delivered to the ion gun **80**, resulting in the deposition of a carbon silicide film, as a second film layer, on the first film layer. During the formation of second film layer, the ion energy was decreasingly varied while the ion current density was increasingly varied, respectively with film-forming time, as shown in FIG. **33**. In this manner, the formation of second film layer was continued for 0.5 minutes to provide the carbon silicide film having a thickness of 400 Å. As a result, a film was formed including the first and second film layers. The thickness of the film thus totaled 1600 Å.

In the same manner as in Example 3, the second film layer of each sample obtained was analyzed by using the secondary mass ion spectrometry (SIMS). As can be appreciated from FIG. **34**, the second film layer had an increased Si content toward its surface so that a concentration gradient of Si was produced in its thickness direction.

The samples obtained were then evaluated for adherence. In evaluating the adherence, a constant load (2 kg) indentation test was conducted using a Vickers penetrator. Fifty samples were subjected to the test and the number of samples that showed delamination of the film from the respective substrata was counted as indicating the level of adherence. For comparative purposes, a silane gas at 1.0×10^{-4} Torr., together with a CH_4 gas, were introduced from the gas inlet line **82**. The ECR plasma CVD method was exclusively utilized to deposit a carbon silicide film on a substrate to a thickness of 1600 Å (Comparative Example 6-1). Likewise, the samples obtained in Comparative Example 6-1 were subjected to the indentation test using a Vickers penetrator for evaluation of adherence.

As a result, the number of samples that showed delamination amounted to 0 in Example 6 but to 40 min Comparative Example 6-1. These results demonstrate that the deposition of the carbon silicide film, as the second film layer, on the diamond-like carbon film, as the first film layer, in accordance with the present invention, improves the adherence of the resulting film to the substrate.

Next, the films respectively obtained in Example 6 and Comparative Example 6-1 were measured for hardness. For comparative purposes, only the above procedure to form the first film layer was followed to solely form a diamond-like carbon film on a substrate to a thickness of 1600 Å (Comparative Example 6-2). Like the above, the film obtained in Comparative Example 3-2 was measured for hardness.

The hardness of the film obtained in Comparative Example 6-1, i.e., the hardness of the amorphous carbon silicide film measured about 2400 Hv, while that of the film obtained in Example 6 measured 3400 Hv. The hardness of the film obtained in Comparative Example 6-2 measured 3500 Hv. These measurement results demonstrate that a film, if constructed by depositing the carbon silicide film, as the second film layer, on the diamond-like carbon film, as the first film layer, is capable of exhibiting the level of hardness almost comparable to that of the diamond-like film.

Next, the films respectively obtained in Example 6 and Comparative Example 6-2 were measured for coefficient of friction. The film of Comparative Example 6-2, a surface of which was defined by the diamond-like carbon film, exhibited a frictional coefficient of 0.18, while the film of Example 6 exhibited a noticeably reduced frictional coefficient of 0.10.

As stated above, a film, if constructed by depositing the carbon nitride or carbon silicide film, as the second film layer, on the diamond-like carbon film as the first film layer, can be functional to exhibit an improved adhesion to the substrate, a higher degree of hardness and a reduced coefficient of friction.

In the above Examples, the CH4 gas is used as a source gas to form the a diamond-like carbon film which constitutes the first film layer. In depositing the second film layer, the nitrogen and silicon ions are further directed onto the first film layer to deposit the carbon nitride or carbon silicide film thereon. It has been found, however, that the same effect can be obtained by directing a carbon gas onto the first film layer to deposit the second film layer thereon. That is, another diamond-like carbon film can be deposited as the second film layer, which has an increased level of hardness compared to the first film layer.

Also, in depositing the second film layer, the mixed ions, composed of nitrogen and oxygen ions, may be directed onto the first film layer to deposit thereon an oxygen-containing carbon nitride film which also exhibits an increased level of hardness and a reduced coefficient of friction.

Although the ion irradiation is used in the above Examples to deposit the second film layer, a radical irradiation may alternatively be used to obtain the same effect. The radical irradiation can be effected by using a radical gun, for example.

The films of the present invention, including those formed by using the film-forming methods in accordance with the fifth through seventh aspects of the present invention, can be employed to constitute protective films for sliding parts such as inner and outer blades of an electric shaver, and for sliding parts such as of a VTR and a compressor including a rotary compressor. They are also applicable for a protective film as a constituent layer of an solar cell, a protective film for sliding parts of a film magnetic head, a propagation film of an SAW device, or a film for a sensor.

The delamination or cutout of the protective film on the sliding surface can be prevented if the value d1/d2, which is the ratio of the thickness d1 of protective film overlying the sliding surface to the thickness d2 of protective film overlying the surface region immediately adjacent the sliding surface, is controlled to be 1 or greater in accordance with the first aspect of the present invention.

In accordance with the second aspect of the present invention, a reduced coefficient of friction and an improved wear-resistance can be imparted to the protective film.

In accordance with the third and fourth aspects of the present invention, the irregularly-surfaced protective film according to the second aspect of the present invention can be formed efficiently.

In accordance with the fifth through seventh aspects of the present invention, the film having the desired functions and adhering well to the substrate can be formed by using the plasma CVD method.

What is claimed is:

1. An electric shaver outer blade having at least one bore formed therein defining a hole for catching a beard, and a sliding surface for sliding contact with an electric shaver inner blade on an inner surface region around said hole for catching the beard, said sliding surface projecting toward said inner blade and having a protective film deposited not only on said sliding surface but also on an outer surface region around said hole in such a manner that d**1**/d**2** is controlled to be within a range of 1.1–3.3 where d**1** is a thickness of the protective film deposited on the sliding surface and d2 is a thickness of the protective film deposited on said outer surface region, the protective film comprising a hard carbon film formed of a diamond and/or amorphous carbon containing a diamond structure and wherein the protective film having a thickness d**1** is disposed across the entire sliding surface of the outer blade during operation, said entire sliding surface being flat.

2. An electric shaver inner blade having at a distal end a sliding surface for sliding contact with an electric shaver outer blade, said inner blade having a protective film deposited not only on said sliding surface but also on a side region immediately adjacent said sliding surface in such a manner that d**1**/d**2** is controlled to be within a range of 1.1–3.3, where d**1** is a thickness of the protective film deposited on the sliding surface and d**2** is a thickness of the protective film deposited on the side region immediately adjacent the sliding surface, the protective film comprising a hard carbon film formed of diamond and/or amorphous carbon containing a diamond structure and wherein the protective film having a thickness d**1** is disposed across the entire sliding surface of the inner blade during a shaving operation.

3. A sliding member having a sliding surface for sliding contact with a cooperative member, said sliding member having a protective film deposited not only on said sliding surface but also on a surface region immediately adjacent the sliding surface in such a manner that d**1**/d**2** is controlled to be within a range of 1.1–3.3, where d**1** is a thickness of the protective film deposited on the sliding surface and d**2** is a thickness of the protective film deposited on the surface region immediately adjacent the sliding surface, the protective film comprising a hard carbon film formed of diamond and/or amorphous carbon containing a diamond structure and wherein the protective film having a thickness d**1** is disposed across the entire sliding surface of the sliding member during a sliding operation.

4. The sliding member of claim **3**, wherein said protective film has a hardness of not less than 1000 Hv.

5. The sliding member of claim **3**, wherein said surface region adjacent the sliding surface is on a surface angularly oriented with respect to the sliding surface.

* * * * *

UNITED STATES DISTRICT COURT
CENTRAL DISTRICT OF CALIFORNIA

NOTICE OF ASSIGNMENT TO UNITED STATES JUDGES

This case has been assigned to District Judge David O. Carter and the assigned Magistrate Judge is Douglas F. McCormick.

The case number on all documents filed with the Court should read as follows:

SACV13-01480 DOC (DFMx)

Pursuant to General Order 05-07 of the United States District Court for the Central District of California, the Magistrate Judge has been designated to hear discovery related motions.

All discovery related motions should be noticed on the calendar of the Magistrate Judge.

Clerk, U. S. District Court

September 23, 2013
Date

By Lori Wagers
Deputy Clerk

NOTICE TO COUNSEL

A copy of this notice must be served with the summons and complaint on all defendants (if a removal action is filed, a copy of this notice must be served on all plaintiffs).

Subsequent documents must be filed at the following location:

☐ Western Division 312 N. Spring Street, G-8 Los Angeles, CA 90012	☒ Southern Division 411 West Fourth St., Ste 1053 Santa Ana, CA 92701	☐ Eastern Division 3470 Twelfth Street, Room 134 Riverside, CA 92501

Failure to file at the proper location will result in your documents being returned to you.

JS 44 (Rev. 12/12)

CIVIL COVER SHEET

The JS 44 civil cover sheet and the information contained herein neither replace nor supplement the filing and service of pleadings or other papers as required by law, except as provided by local rules of court. This form, approved by the Judicial Conference of the United States in September 1974, is required for the use of the Clerk of Court for the purpose of initiating the civil docket sheet. *(SEE INSTRUCTIONS ON NEXT PAGE OF THIS FORM.)*

I. (a) PLAINTIFFS
DIAMOND COATING TECHNOLOGIES, LLC

DEFENDANTS
HYUNDAI MOTOR AMERICA AND HYUNDAI MOTOR COMPANY

(b) County of Residence of First Listed Plaintiff ______
(EXCEPT IN U.S. PLAINTIFF CASES)

County of Residence of First Listed Defendant Orange
(IN U.S. PLAINTIFF CASES ONLY)
NOTE: IN LAND CONDEMNATION CASES, USE THE LOCATION OF THE TRACT OF LAND INVOLVED.

(c) Attorneys *(Firm Name, Address, and Telephone Number)*
Susman Godfrey L.L.P., 1901 Avenue of the Stars, Ste. 950
Los Angeles, CA 90067

Attorneys *(If Known)*

II. BASIS OF JURISDICTION *(Place an "X" in One Box Only)*

☐ 1 U.S. Government Plaintiff
☒ 3 Federal Question *(U.S. Government Not a Party)*
☐ 2 U.S. Government Defendant
☐ 4 Diversity *(Indicate Citizenship of Parties in Item III)*

III. CITIZENSHIP OF PRINCIPAL PARTIES *(Place an "X" in One Box for Plaintiff and One Box for Defendant)* *(For Diversity Cases Only)*

	PTF	DEF		PTF	DEF
Citizen of This State	☐ 1	☐ 1	Incorporated *or* Principal Place of Business In This State	☐ 4	☐ 4
Citizen of Another State	☐ 2	☐ 2	Incorporated *and* Principal Place of Business In Another State	☐ 5	☐ 5
Citizen or Subject of a Foreign Country	☐ 3	☐ 3	Foreign Nation	☐ 6	☐ 6

IV. NATURE OF SUIT *(Place an "X" in One Box Only)*

CONTRACT
☐ 110 Insurance
☐ 120 Marine
☐ 130 Miller Act
☐ 140 Negotiable Instrument
☐ 150 Recovery of Overpayment & Enforcement of Judgment
☐ 151 Medicare Act
☐ 152 Recovery of Defaulted Student Loans (Excludes Veterans)
☐ 153 Recovery of Overpayment of Veteran's Benefits
☐ 160 Stockholders' Suits
☐ 190 Other Contract
☐ 195 Contract Product Liability
☐ 196 Franchise

REAL PROPERTY
☐ 210 Land Condemnation
☐ 220 Foreclosure
☐ 230 Rent Lease & Ejectment
☐ 240 Torts to Land
☐ 245 Tort Product Liability
☐ 290 All Other Real Property

TORTS

PERSONAL INJURY
☐ 310 Airplane
☐ 315 Airplane Product Liability
☐ 320 Assault, Libel & Slander
☐ 330 Federal Employers' Liability
☐ 340 Marine
☐ 345 Marine Product Liability
☐ 350 Motor Vehicle
☐ 355 Motor Vehicle Product Liability
☐ 360 Other Personal Injury
☐ 362 Personal Injury - Medical Malpractice

PERSONAL INJURY
☐ 365 Personal Injury - Product Liability
☐ 367 Health Care/ Pharmaceutical Personal Injury Product Liability
☐ 368 Asbestos Personal Injury Product Liability

PERSONAL PROPERTY
☐ 370 Other Fraud
☐ 371 Truth in Lending
☐ 380 Other Personal Property Damage
☐ 385 Property Damage Product Liability

CIVIL RIGHTS
☐ 440 Other Civil Rights
☐ 441 Voting
☐ 442 Employment
☐ 443 Housing/ Accommodations
☐ 445 Amer. w/Disabilities - Employment
☐ 446 Amer. w/Disabilities - Other
☐ 448 Education

PRISONER PETITIONS
Habeas Corpus:
☐ 463 Alien Detainee
☐ 510 Motions to Vacate Sentence
☐ 530 General
☐ 535 Death Penalty
Other:
☐ 540 Mandamus & Other
☐ 550 Civil Rights
☐ 555 Prison Condition
☐ 560 Civil Detainee - Conditions of Confinement

FORFEITURE/PENALTY
☐ 625 Drug Related Seizure of Property 21 USC 881
☐ 690 Other

LABOR
☐ 710 Fair Labor Standards Act
☐ 720 Labor/Management Relations
☐ 740 Railway Labor Act
☐ 751 Family and Medical Leave Act
☐ 790 Other Labor Litigation
☐ 791 Employee Retirement Income Security Act

IMMIGRATION
☐ 462 Naturalization Application
☐ 465 Other Immigration Actions

BANKRUPTCY
☐ 422 Appeal 28 USC 158
☐ 423 Withdrawal 28 USC 157

PROPERTY RIGHTS
☐ 820 Copyrights
☒ 830 Patent
☐ 840 Trademark

SOCIAL SECURITY
☐ 861 HIA (1395ff)
☐ 862 Black Lung (923)
☐ 863 DIWC/DIWW (405(g))
☐ 864 SSID Title XVI
☐ 865 RSI (405(g))

FEDERAL TAX SUITS
☐ 870 Taxes (U.S. Plaintiff or Defendant)
☐ 871 IRS—Third Party 26 USC 7609

OTHER STATUTES
☐ 375 False Claims Act
☐ 400 State Reapportionment
☐ 410 Antitrust
☐ 430 Banks and Banking
☐ 450 Commerce
☐ 460 Deportation
☐ 470 Racketeer Influenced and Corrupt Organizations
☐ 480 Consumer Credit
☐ 490 Cable/Sat TV
☐ 850 Securities/Commodities/ Exchange
☐ 890 Other Statutory Actions
☐ 891 Agricultural Acts
☐ 893 Environmental Matters
☐ 895 Freedom of Information Act
☐ 896 Arbitration
☐ 899 Administrative Procedure Act/Review or Appeal of Agency Decision
☐ 950 Constitutionality of State Statutes

V. ORIGIN *(Place an "X" in One Box Only)*

☒ 1 Original Proceeding
☐ 2 Removed from State Court
☐ 3 Remanded from Appellate Court
☐ 4 Reinstated or Reopened
☐ 5 Transferred from Another District *(specify)*
☐ 6 Multidistrict Litigation

VI. CAUSE OF ACTION
Cite the U.S. Civil Statute under which you are filing *(Do not cite jurisdictional statutes unless diversity)*:
28 U.S.C. §§ 1331 and 1338(a) and 35 U.S.C. §§ 1 et seq.
Brief description of cause:
COMPLAINT FOR PATENT INFRINGEMENT

VII. REQUESTED IN COMPLAINT:
☐ CHECK IF THIS IS A CLASS ACTION UNDER RULE 23, F.R.Cv.P.
DEMAND $
CHECK YES only if demanded in complaint:
JURY DEMAND: ☒ Yes ☐ No

VIII. RELATED CASE(S) IF ANY *(See instructions)*: Diamond Coating Technologies, LLC v. Nissan North America, and Nissan Motor Co., Ltd filed concurrently
JUDGE TBD DOCKET NUMBER TBD

DATE 09/23/2013
SIGNATURE OF ATTORNEY OF RECORD Kathryn P. Hoek

FOR OFFICE USE ONLY

RECEIPT # ______ AMOUNT ______ APPLYING IFP ______ JUDGE ______ MAG. JUDGE ______

SACV13-01480 DOC (DFMx)

JS 44 Reverse (Rev. 12/12)

INSTRUCTIONS FOR ATTORNEYS COMPLETING CIVIL COVER SHEET FORM JS 44

Authority For Civil Cover Sheet

The JS 44 civil cover sheet and the information contained herein neither replaces nor supplements the filings and service of pleading or other papers as required by law, except as provided by local rules of court. This form, approved by the Judicial Conference of the United States in September 1974, is required for the use of the Clerk of Court for the purpose of initiating the civil docket sheet. Consequently, a civil cover sheet is submitted to the Clerk of Court for each civil complaint filed. The attorney filing a case should complete the form as follows:

I.(a) **Plaintiffs-Defendants.** Enter names (last, first, middle initial) of plaintiff and defendant. If the plaintiff or defendant is a government agency, use only the full name or standard abbreviations. If the plaintiff or defendant is an official within a government agency, identify first the agency and then the official, giving both name and title.

(b) **County of Residence.** For each civil case filed, except U.S. plaintiff cases, enter the name of the county where the first listed plaintiff resides at the time of filing. In U.S. plaintiff cases, enter the name of the county in which the first listed defendant resides at the time of filing. (NOTE: In land condemnation cases, the county of residence of the "defendant" is the location of the tract of land involved.)

(c) **Attorneys.** Enter the firm name, address, telephone number, and attorney of record. If there are several attorneys, list them on an attachment, noting in this section "(see attachment)".

II. **Jurisdiction.** The basis of jurisdiction is set forth under Rule 8(a), F.R.Cv.P., which requires that jurisdictions be shown in pleadings. Place an "X" in one of the boxes. If there is more than one basis of jurisdiction, precedence is given in the order shown below.
United States plaintiff. (1) Jurisdiction based on 28 U.S.C. 1345 and 1348. Suits by agencies and officers of the United States are included here.
United States defendant. (2) When the plaintiff is suing the United States, its officers or agencies, place an "X" in this box.
Federal question. (3) This refers to suits under 28 U.S.C. 1331, where jurisdiction arises under the Constitution of the United States, an amendment to the Constitution, an act of Congress or a treaty of the United States. In cases where the U.S. is a party, the U.S. plaintiff or defendant code takes precedence, and box 1 or 2 should be marked.
Diversity of citizenship. (4) This refers to suits under 28 U.S.C. 1332, where parties are citizens of different states. When Box 4 is checked, the citizenship of the different parties must be checked. (See Section III below; **NOTE: federal question actions take precedence over diversity cases.)**

III. **Residence (citizenship) of Principal Parties.** This section of the JS 44 is to be completed if diversity of citizenship was indicated above. Mark this section for each principal party.

IV. **Nature of Suit.** Place an "X" in the appropriate box. If the nature of suit cannot be determined, be sure the cause of action, in Section VI below, is sufficient to enable the deputy clerk or the statistical clerk(s) in the Administrative Office to determine the nature of suit. If the cause fits more than one nature of suit, select the most definitive.

V. **Origin.** Place an "X" in one of the six boxes.
Original Proceedings. (1) Cases which originate in the United States district courts.
Removed from State Court. (2) Proceedings initiated in state courts may be removed to the district courts under Title 28 U.S.C., Section 1441. When the petition for removal is granted, check this box.
Remanded from Appellate Court. (3) Check this box for cases remanded to the district court for further action. Use the date of remand as the filing date.
Reinstated or Reopened. (4) Check this box for cases reinstated or reopened in the district court. Use the reopening date as the filing date.
Transferred from Another District. (5) For cases transferred under Title 28 U.S.C. Section 1404(a). Do not use this for within district transfers or multidistrict litigation transfers.
Multidistrict Litigation. (6) Check this box when a multidistrict case is transferred into the district under authority of Title 28 U.S.C. Section 1407. When this box is checked, do not check (5) above.

VI. **Cause of Action.** Report the civil statute directly related to the cause of action and give a brief description of the cause. **Do not cite jurisdictional statutes unless diversity.** Example: U.S. Civil Statute: 47 USC 553 Brief Description: Unauthorized reception of cable service

VII. **Requested in Complaint.** Class Action. Place an "X" in this box if you are filing a class action under Rule 23, F.R.Cv.P.
Demand. In this space enter the actual dollar amount being demanded or indicate other demand, such as a preliminary injunction.
Jury Demand. Check the appropriate box to indicate whether or not a jury is being demanded.

VIII. **Related Cases.** This section of the JS 44 is used to reference related pending cases, if any. If there are related pending cases, insert the docket numbers and the corresponding judge names for such cases.

Date and Attorney Signature. Date and sign the civil cover sheet.